



The
University
Of
Sheffield.

THE
ROYAL
SOCIETY

Clustering in the era of Gaia DR2

Richard Parker

(Royal Society Dorothy Hodgkin Fellow, University of Sheffield)



The
University
Of
Sheffield.

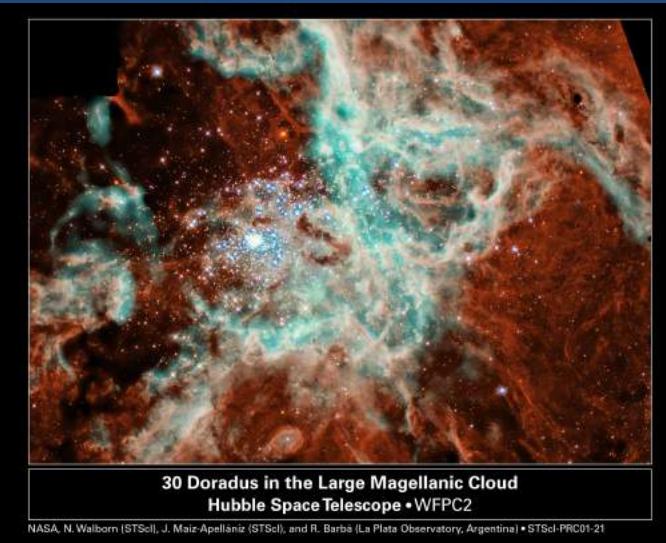
Where are most stars born?



Chamaeleon I (G. Rhemann, M Jager)



Sco Cen (A. Fujii)



30 Doradus in the Large Magellanic Cloud
Hubble Space Telescope • WFPC2

NASA, N. Walborn (STScI), J. Maiz Apellaniz (STScI), and R. Barbs (La Plata Observatory, Argentina) • STScI-PRC01-21

30 Doradus (Walborn et al)

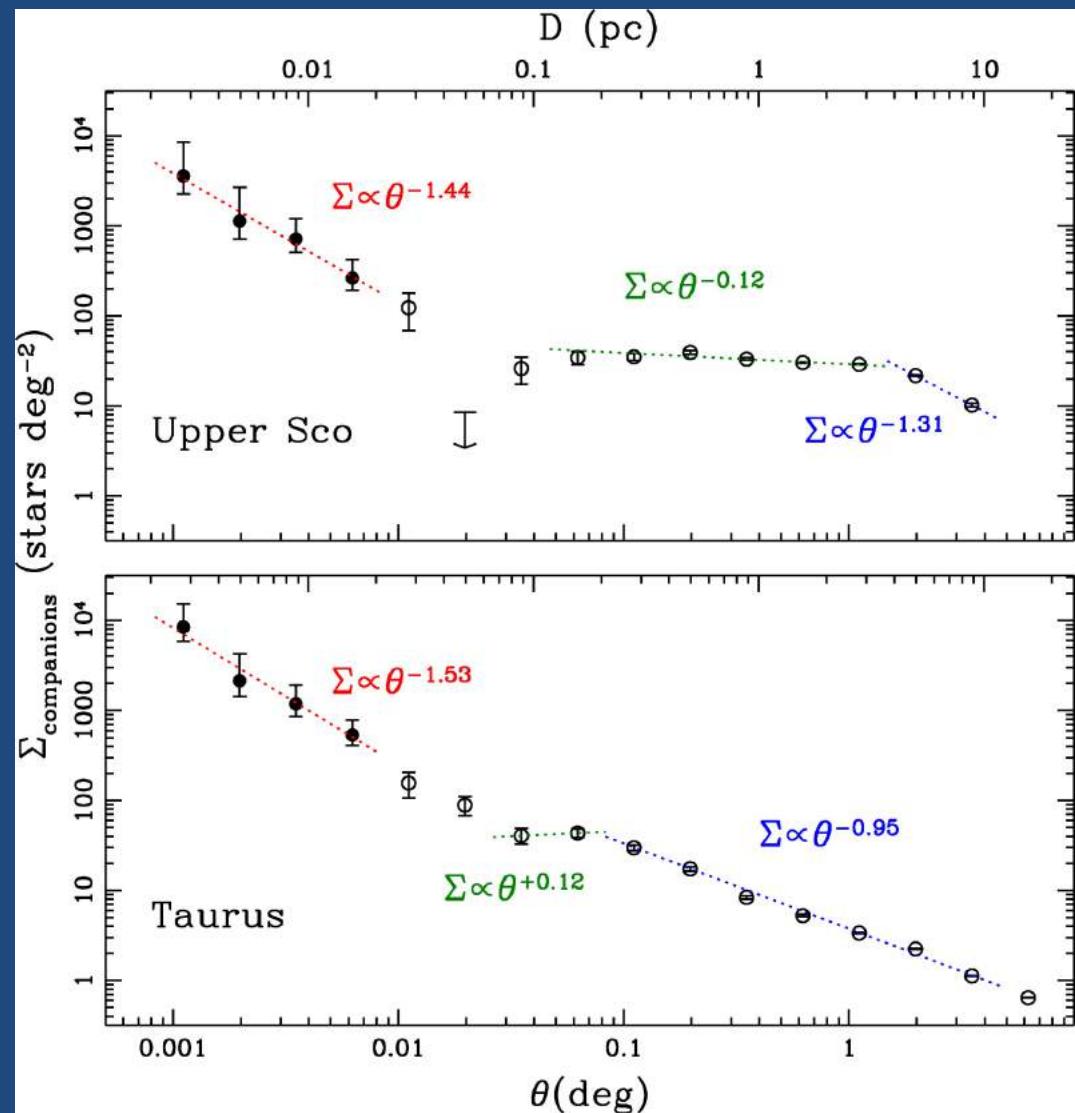


ONC (McCaughrean et al)



Quantifying structure and morphology

- Larson (1995) – two-point correlation function in Taurus
- Break in power law corresponds to Jeans length (Simon 1997), though see Bate et al (1998)
- Kraus & Hillenbrand 2008 – tracing dynamical evolution?





Quantifying structure and morphology

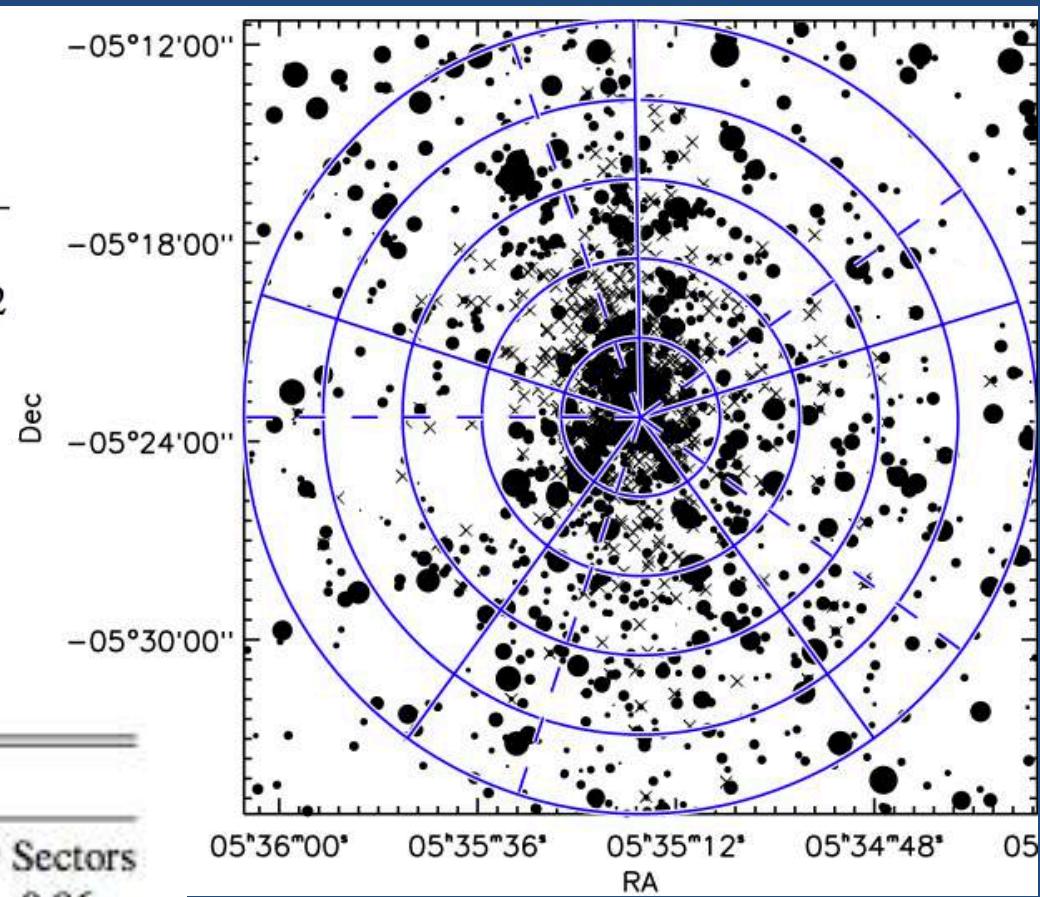
- Angular dispersion parameter - Da Rio et al 2014; Jaehnig et al 2015, see also Gutermuth et al 2005

$$\delta_{\text{ADP},N} = \sqrt{\frac{1}{(N-1)\bar{n}} \sum_{i=1}^N (n_i - \bar{n})^2}$$

Average Measured Dispersion $\delta_{\text{ADP},N}$

50 Stars per Annulus

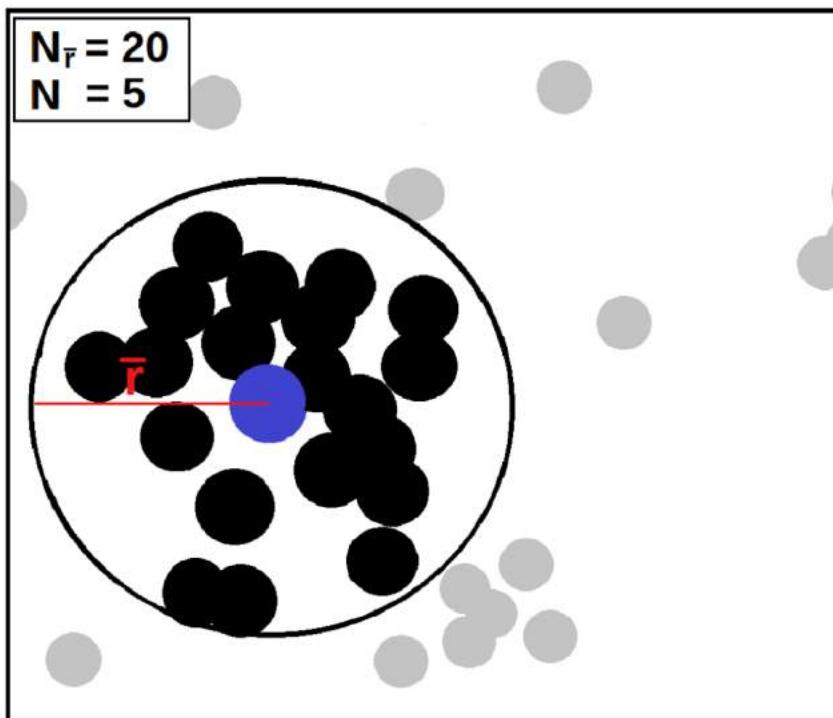
	4 Sectors	6 Sectors	9 Sectors
Globular clusters	0.92	0.95	0.96
ONC	1.39	1.40	1.31
Taurus	2.77	3.01	3.03



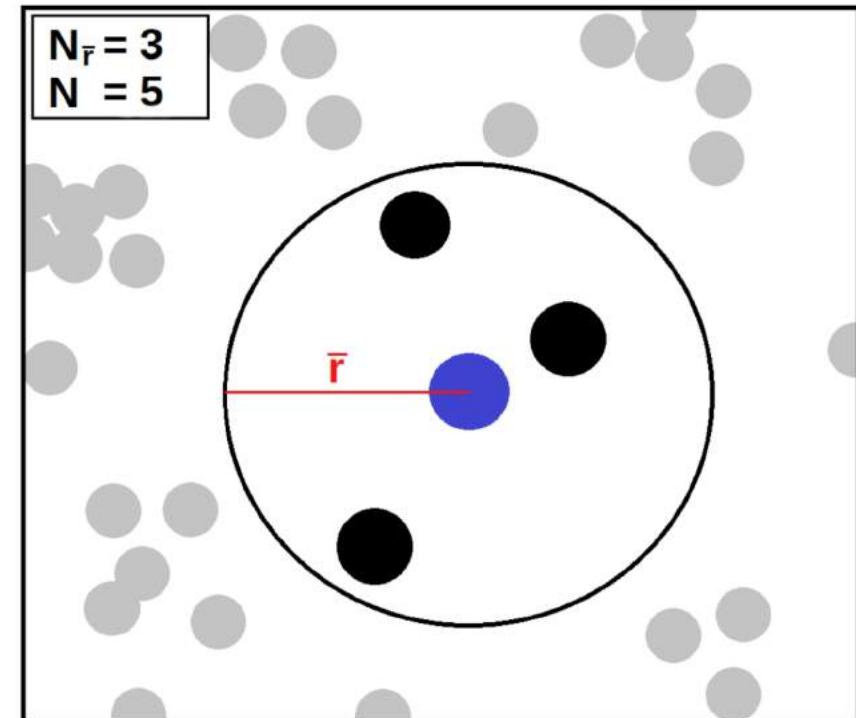


Quantifying structure and morphology

- Buckner et al 2019 'INDICATE'



$$I = 20/5 = 4$$

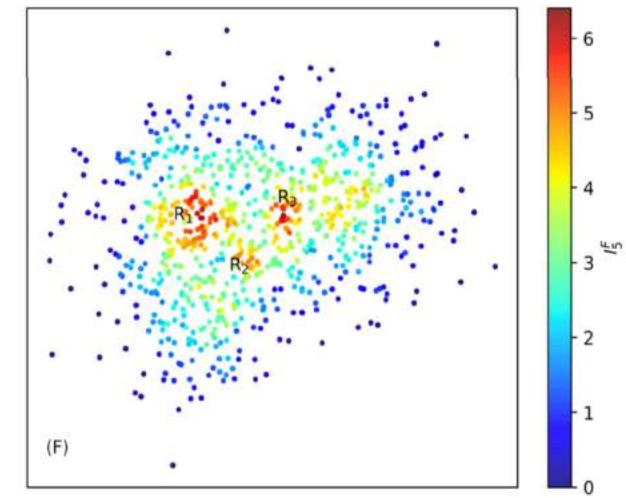
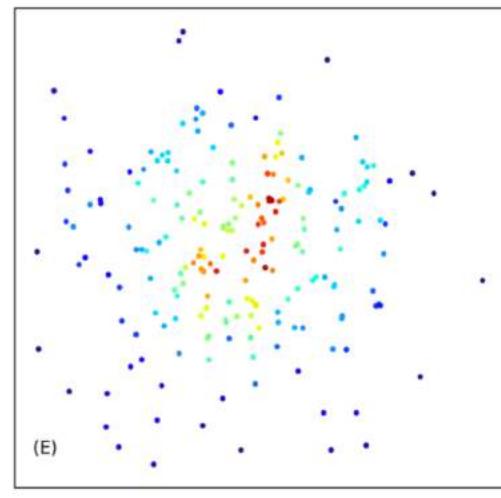
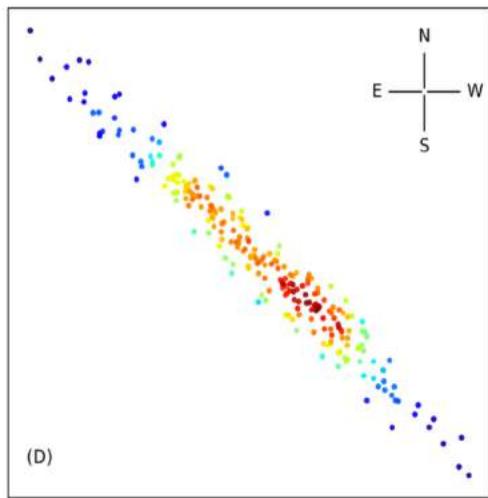


$$I = 3/5 = 0.6$$



Quantifying structure and morphology

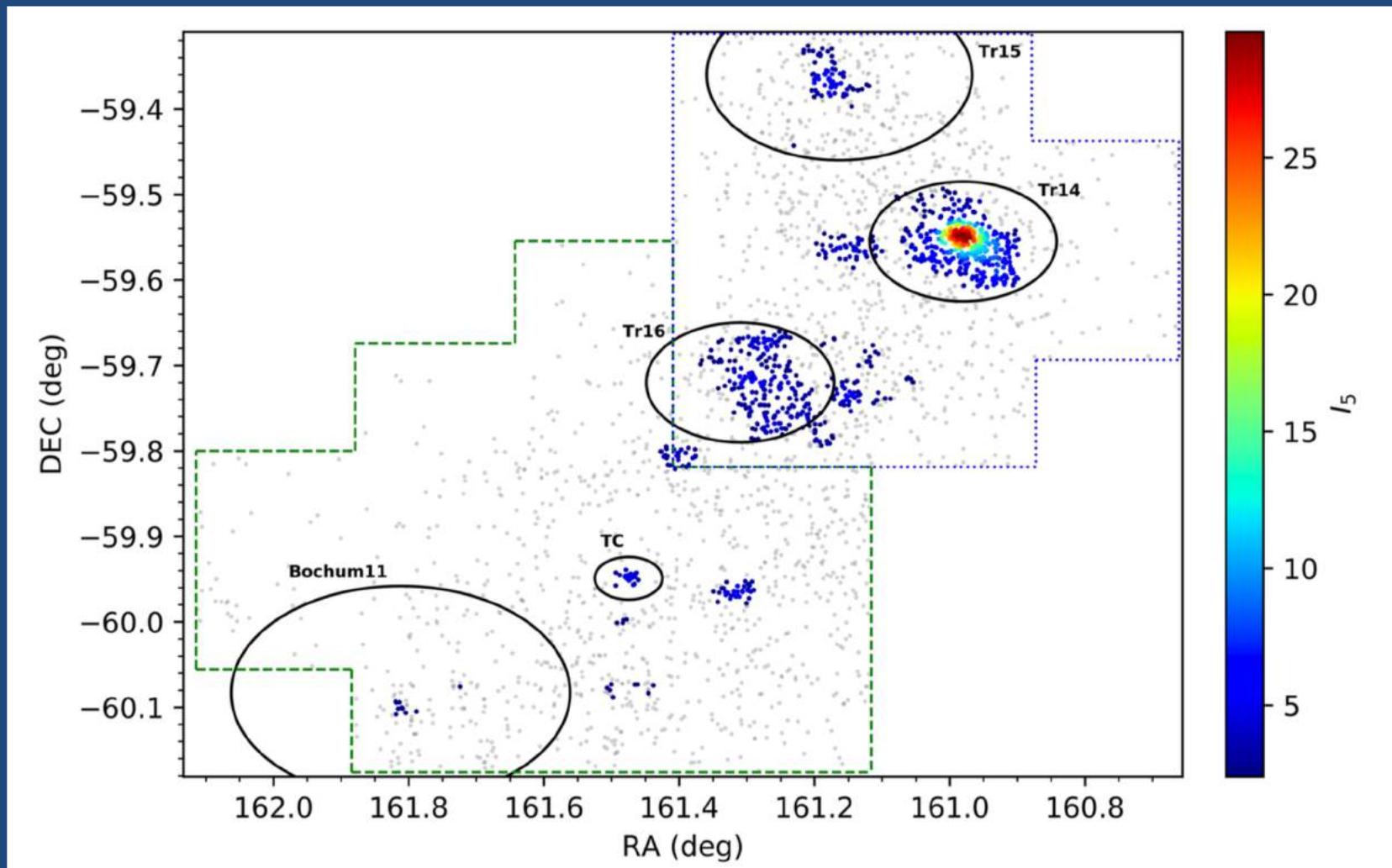
- Buckner et al 2019 'INDICATE'





Quantifying structure and morphology

- Buckner et al 2019 'INDICATE'

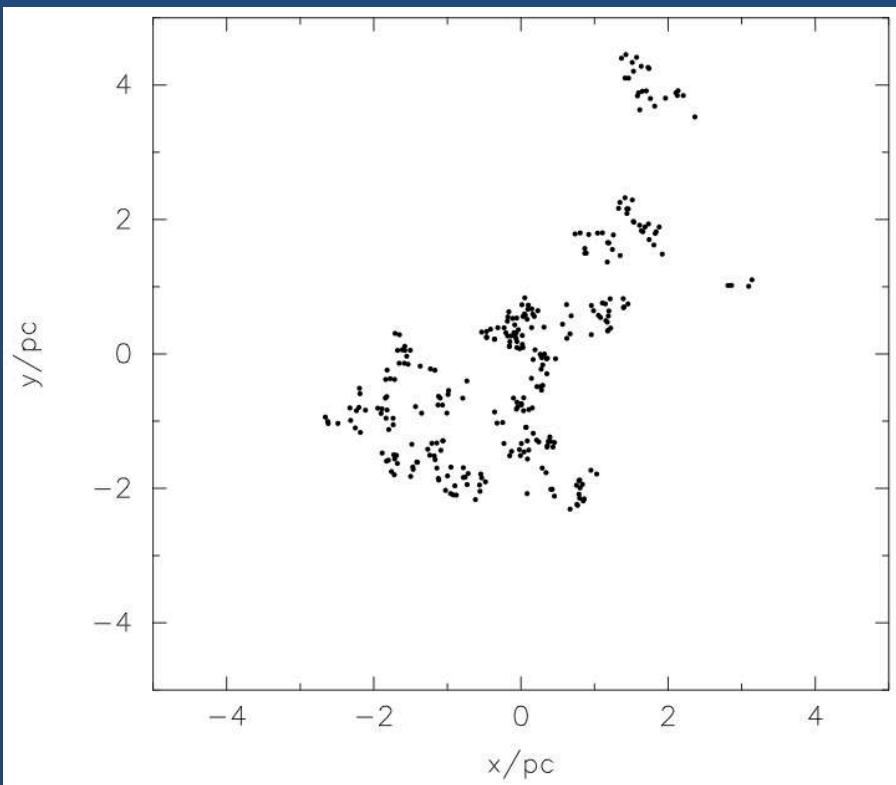




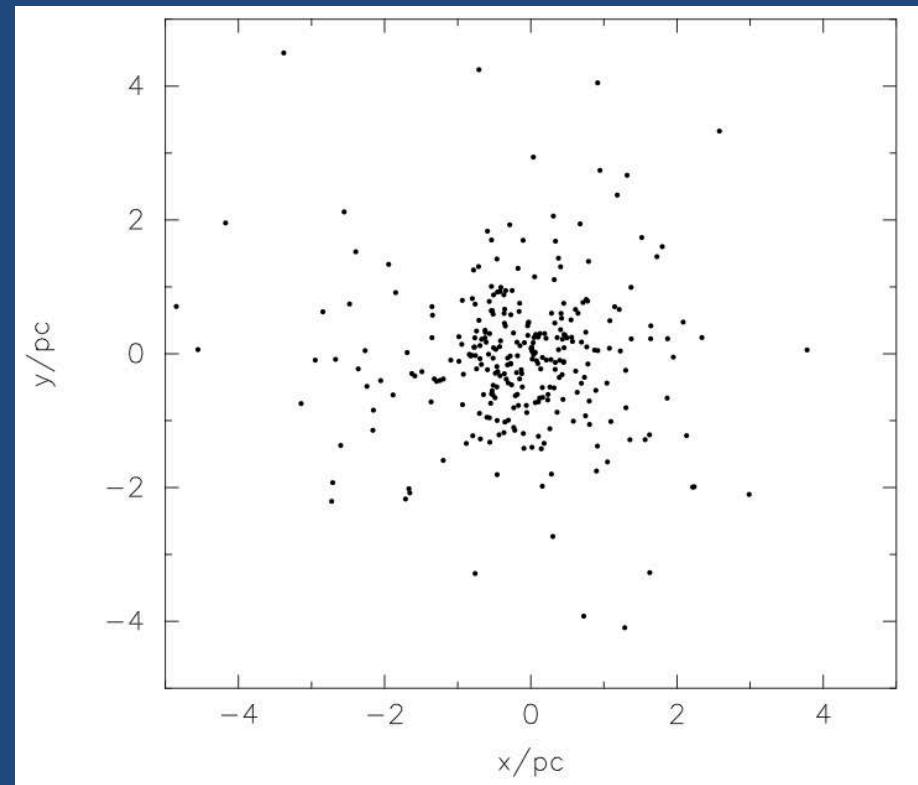
Quantifying structure and morphology

- Measuring structure: the Q-parameter - Cartwright & Whitworth (2004), Cartwright 2009, Schmeja & Klessen 2006, Lomax et al 2011, Jaffa et al 2017, many others...
- Divides mean MST length by mean separation length

$$Q = \frac{\bar{m}}{\bar{s}}$$



substructured fractal



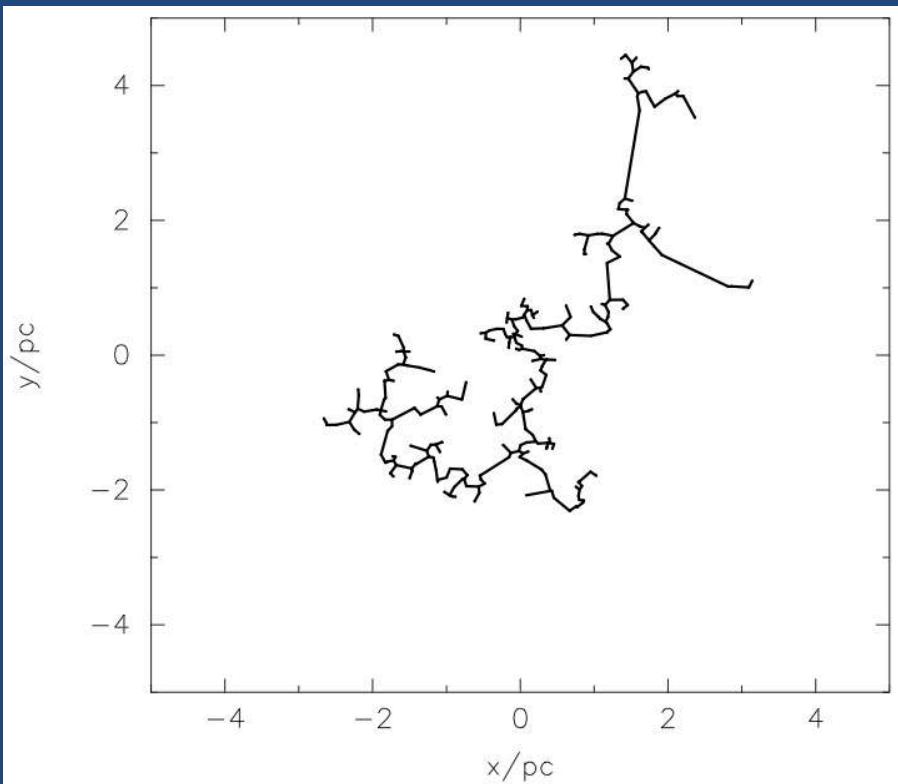
centrally concentrated Plummer sphere



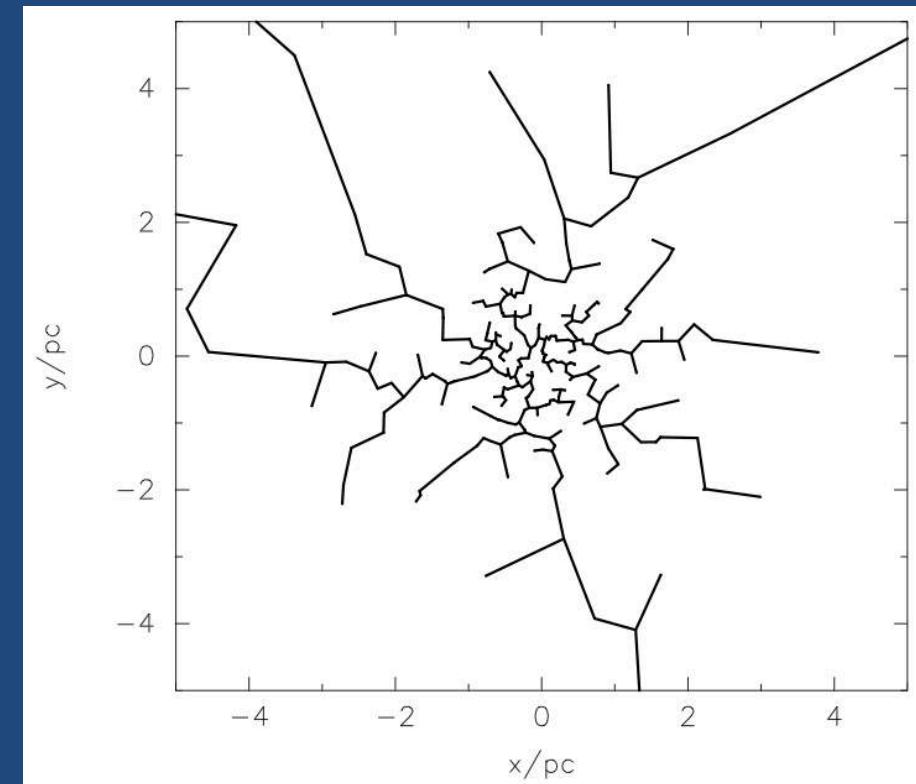
Quantifying structure and morphology

- Measuring structure: the Q-parameter - Cartwright & Whitworth (2004), Cartwright 2009, Schmeja & Klessen 2006, Lomax et al 2011, Jaffa et al 2017, many others...
- Divides mean MST length by mean separation length

$$Q = \frac{\bar{m}}{\bar{s}}$$



$Q \sim 0.4$



$Q \sim 1.2$

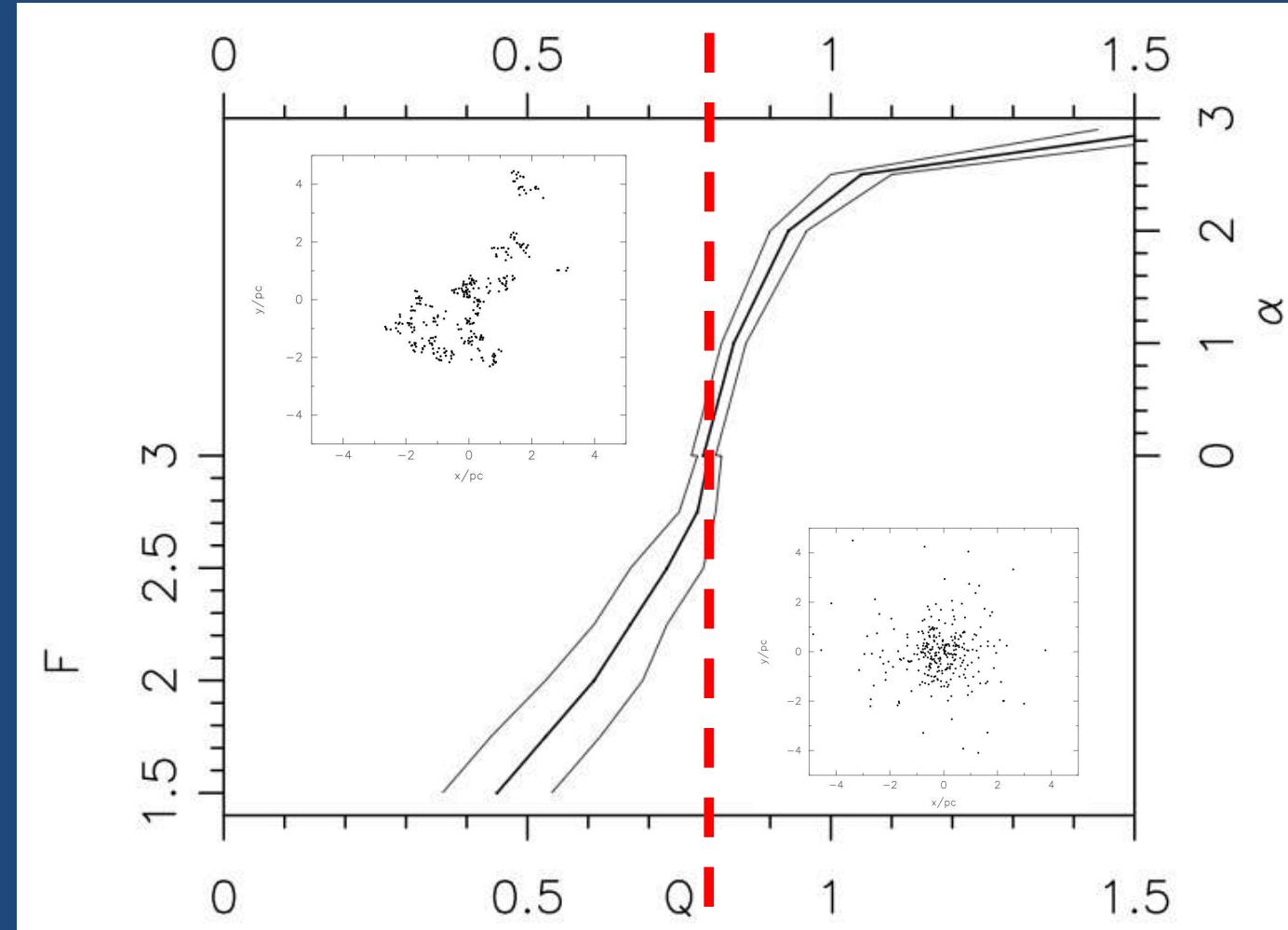


Quantifying structure and morphology

- Measuring structure: the Q-parameter - Cartwright & Whitworth (2004)
- Divides mean MST length by mean separation length:

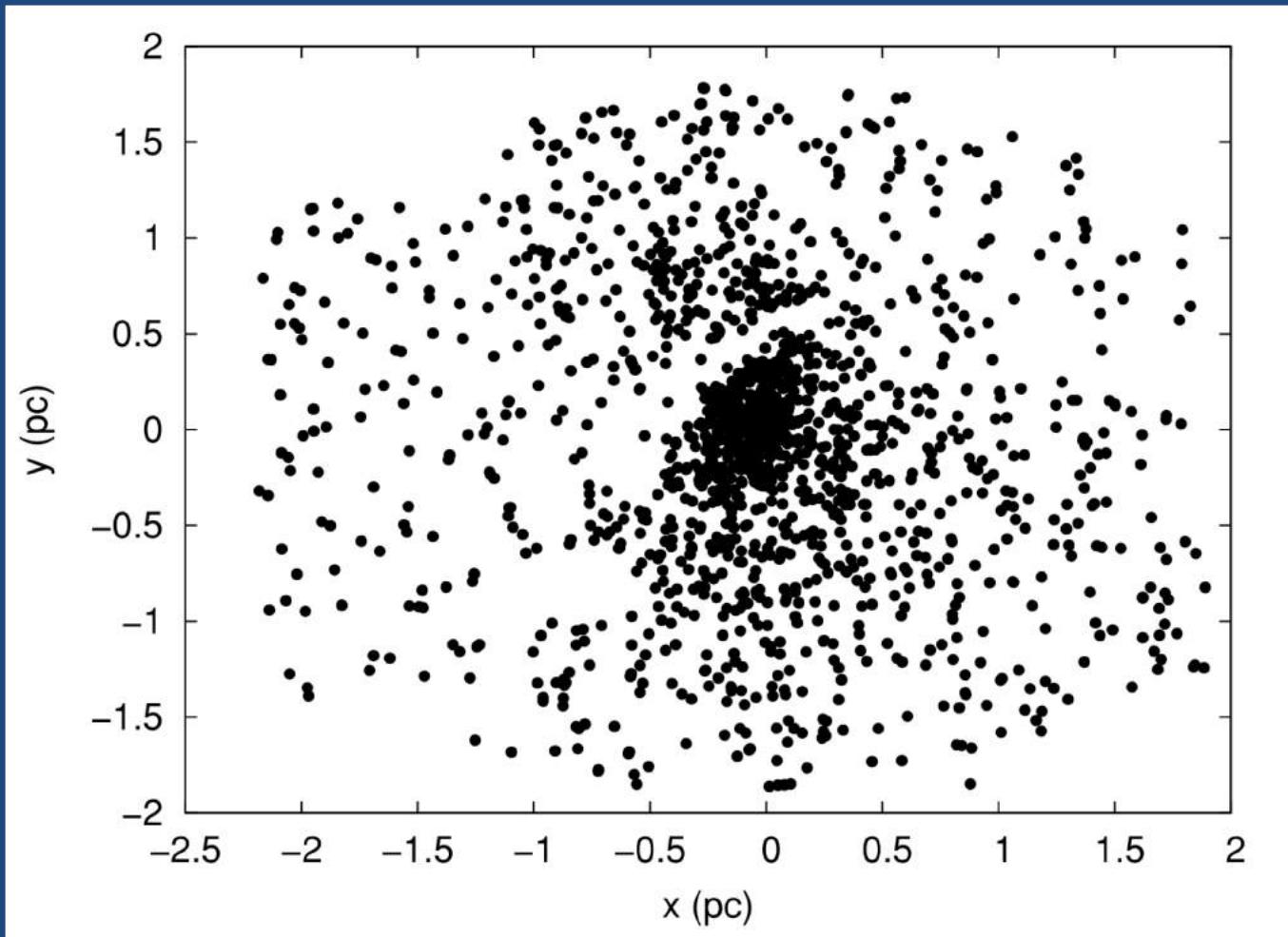
$$Q = \frac{\bar{m}}{\bar{s}}$$

- $Q > 0.8$ = radially concentrated
- $Q < 0.8$ = substructured
- Many young star-forming regions substructured (e.g. Cartwright & Whitworth 2004; Schmeja et al 2008; Sanchez & Alfaro 2009)



Issues – (variable) extinction

- More substructure/less central concentration in presence of extinction
(Bastian et al 2009; Parker & Meyer 2012)

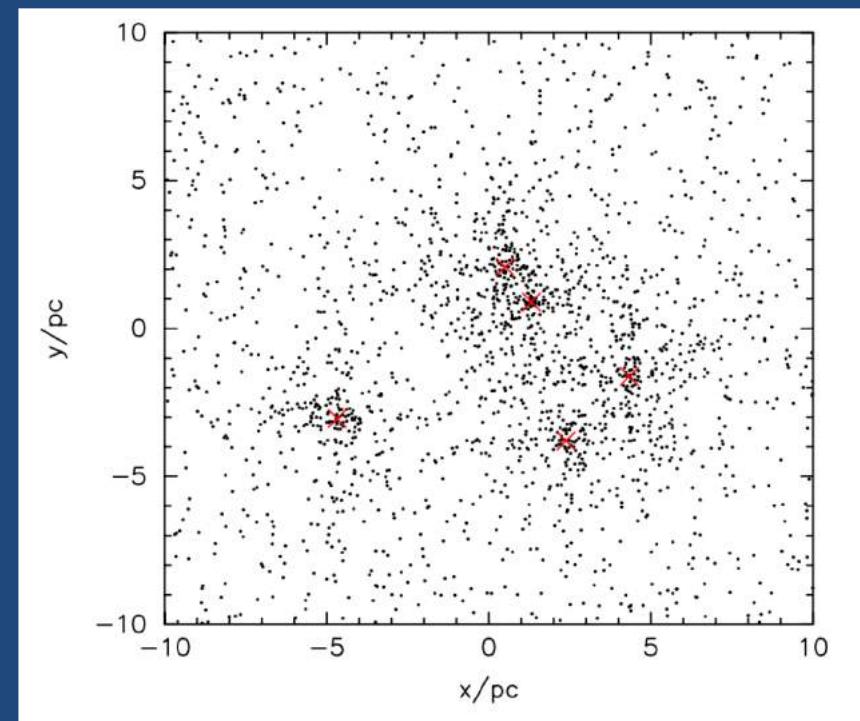
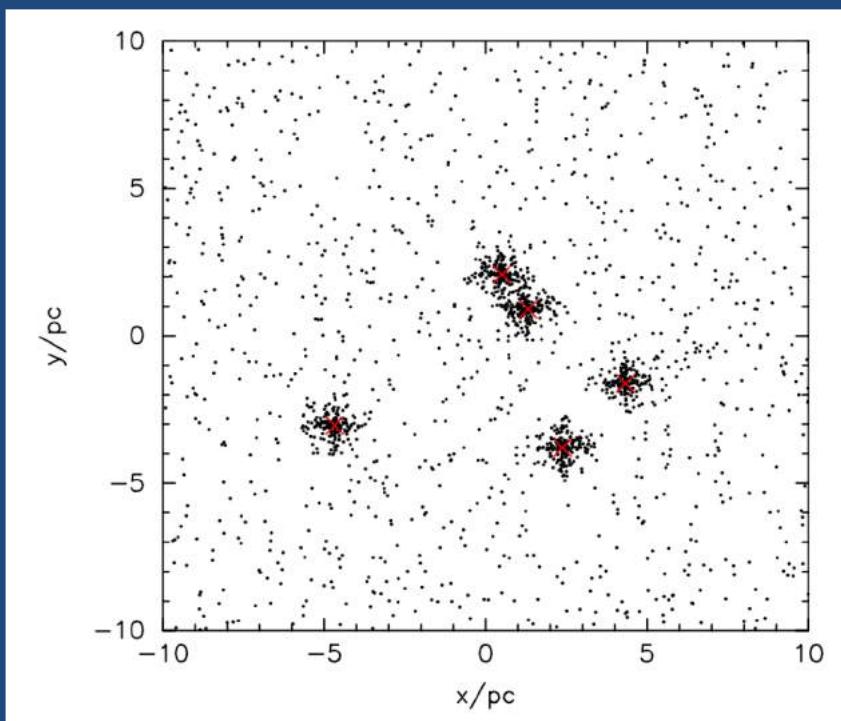


ONC data (Hillenbrand 1997, image from King et al 2012)



Issues – fore/background contamination

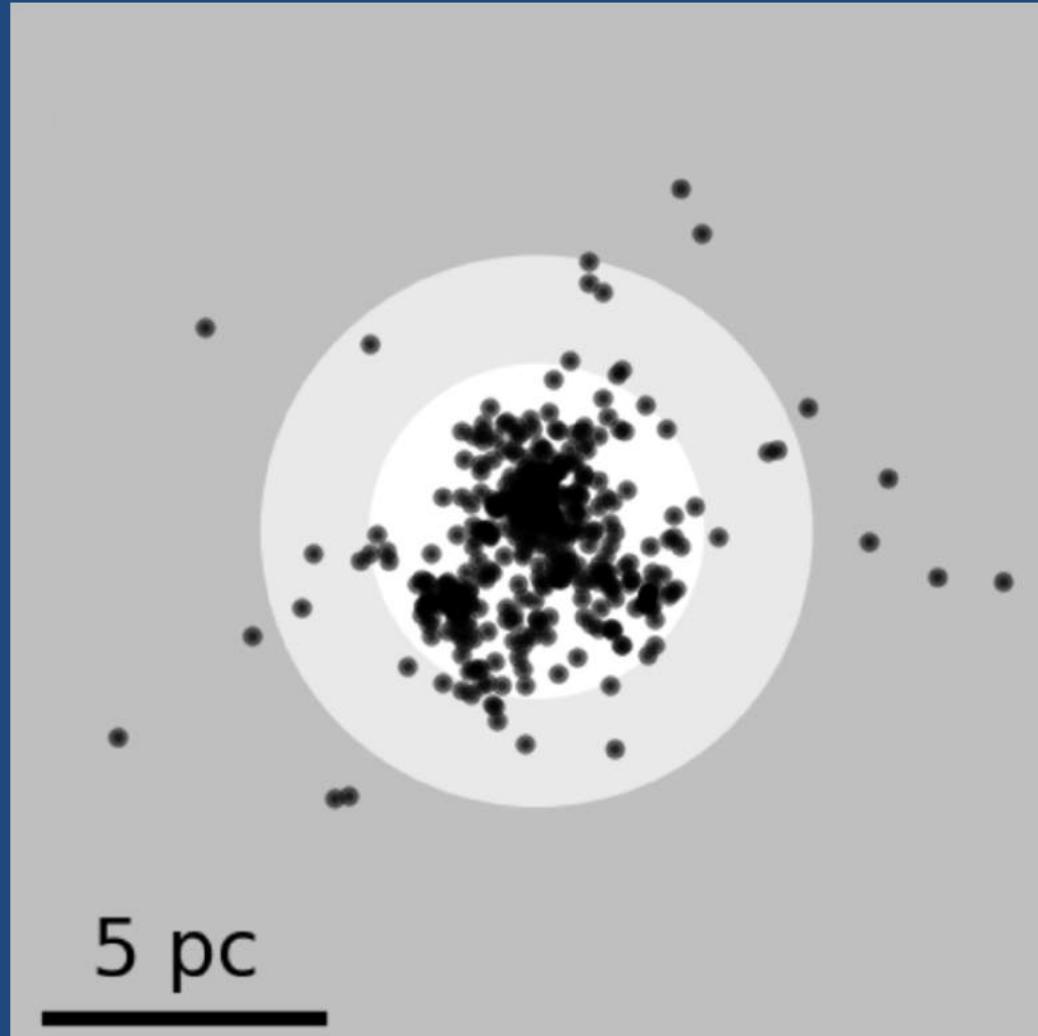
- Need accurate membership probabilities





Issues – choosing boundaries

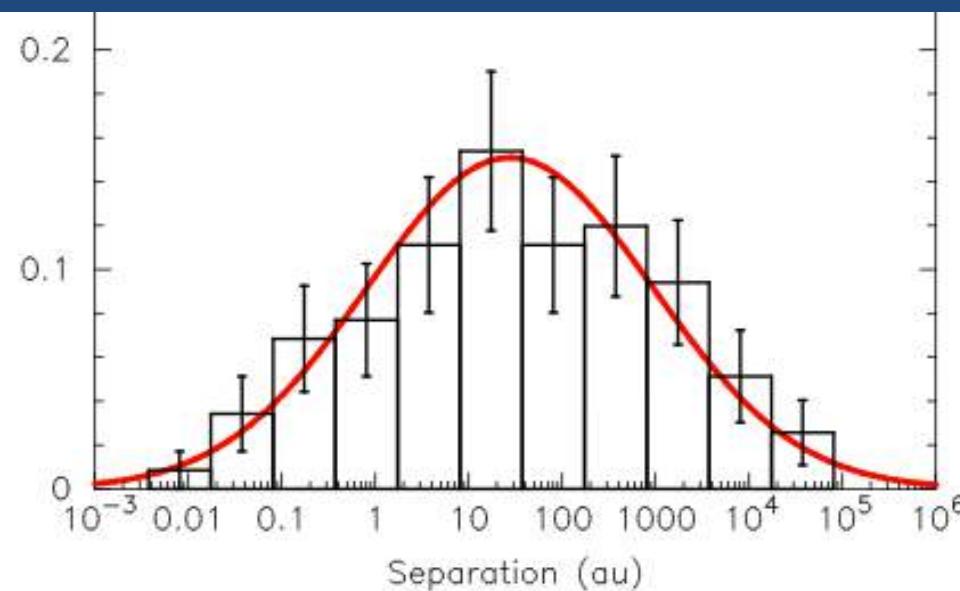
- Outliers usually make a region appear more centrally concentrated



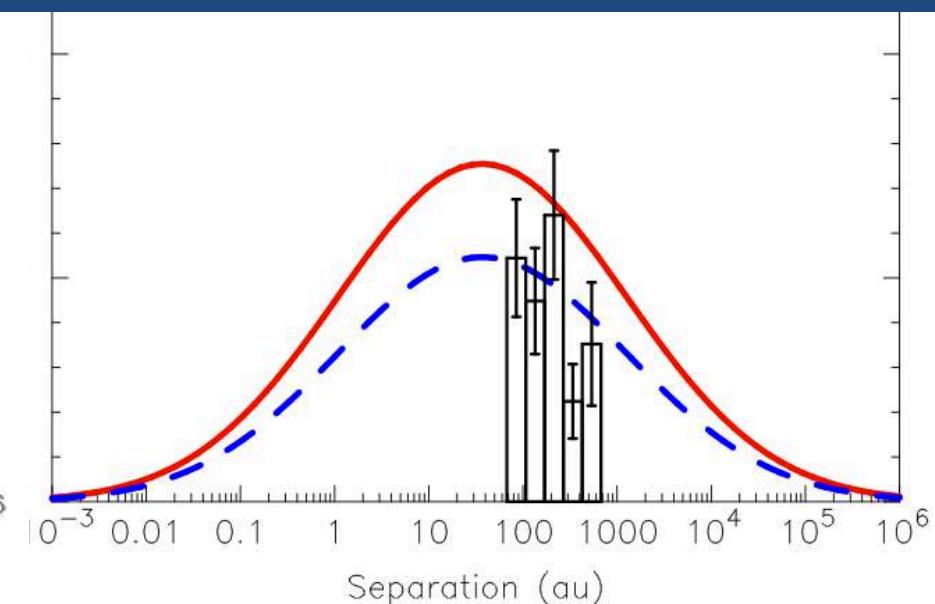


Issues – wide binaries

- Binary properties – limited data for SF regions



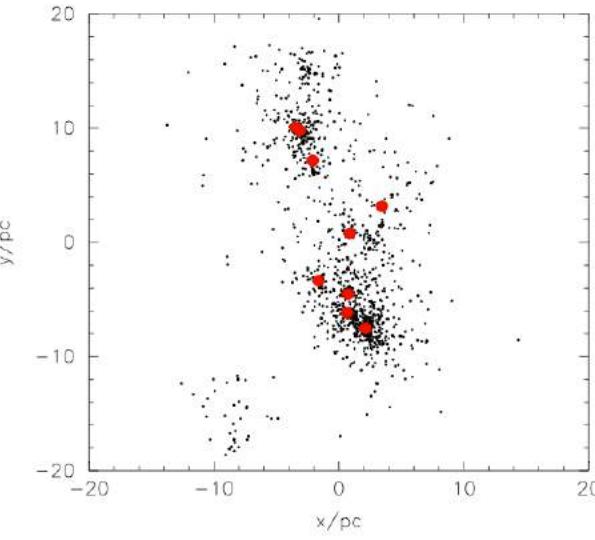
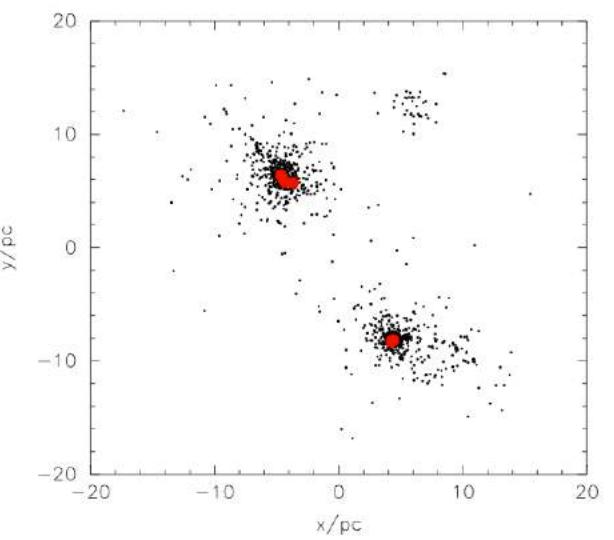
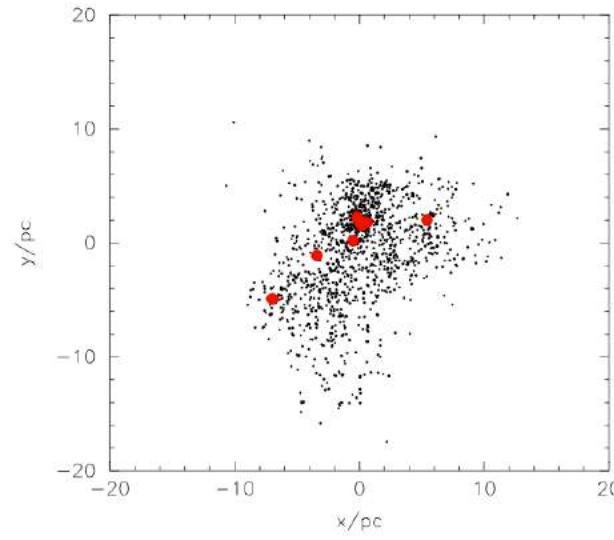
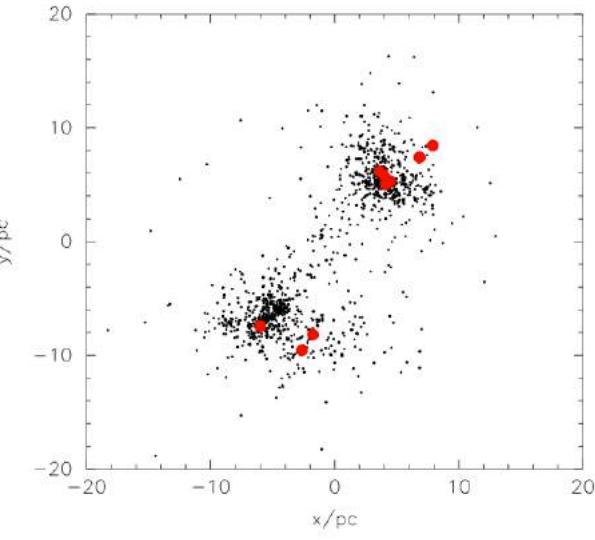
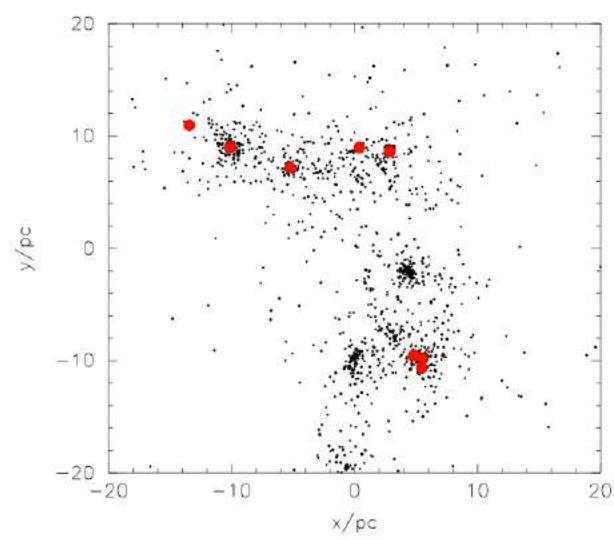
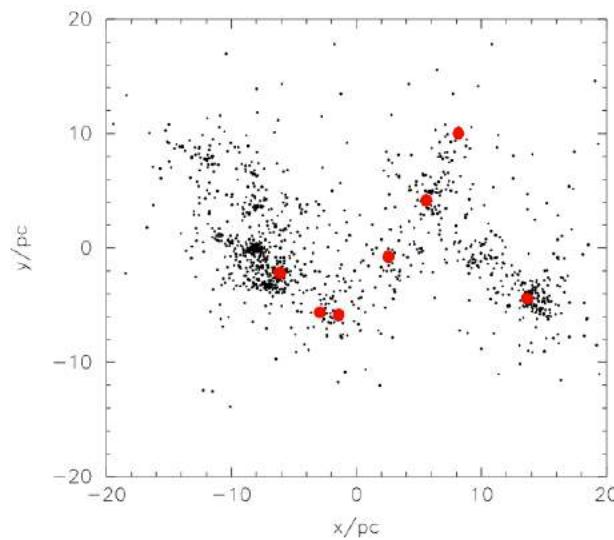
The Field (Raghavan et al 2010)



The ONC (Reipurth et al 2007)



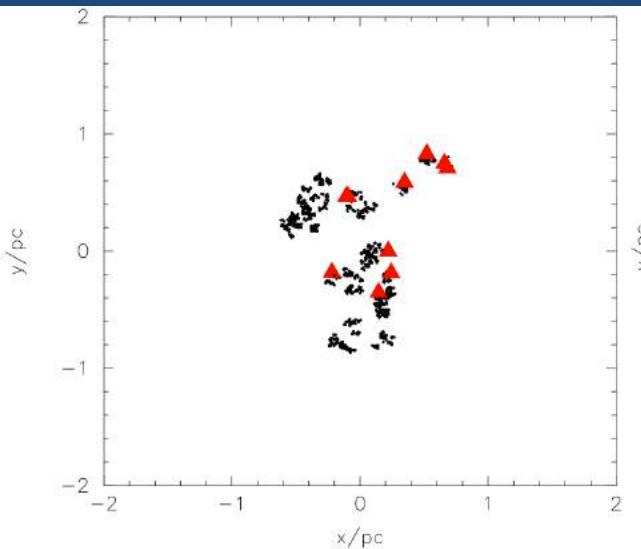
Morphological stochasticity



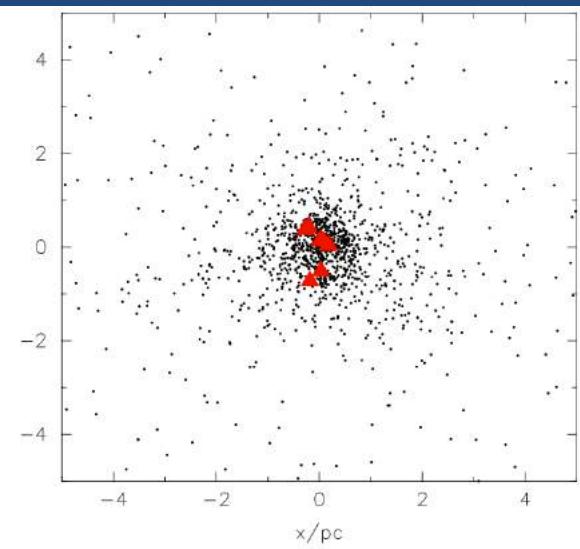


Dynamical evolution

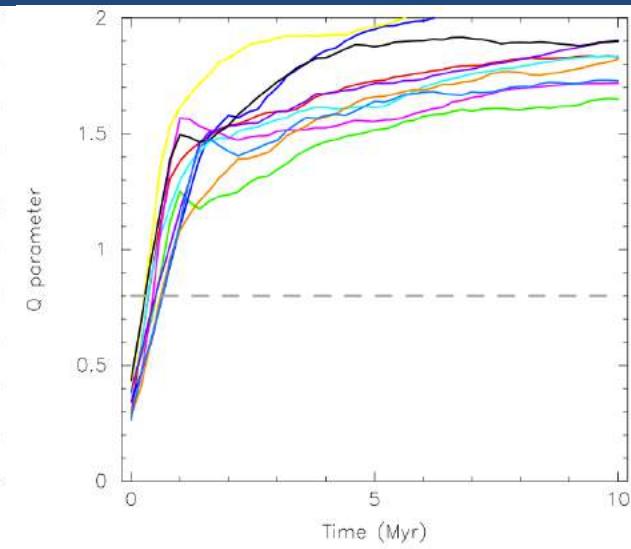
- Evolution of the Q-parameter in a collapsing star-forming region:



0 Myr



5 Myr

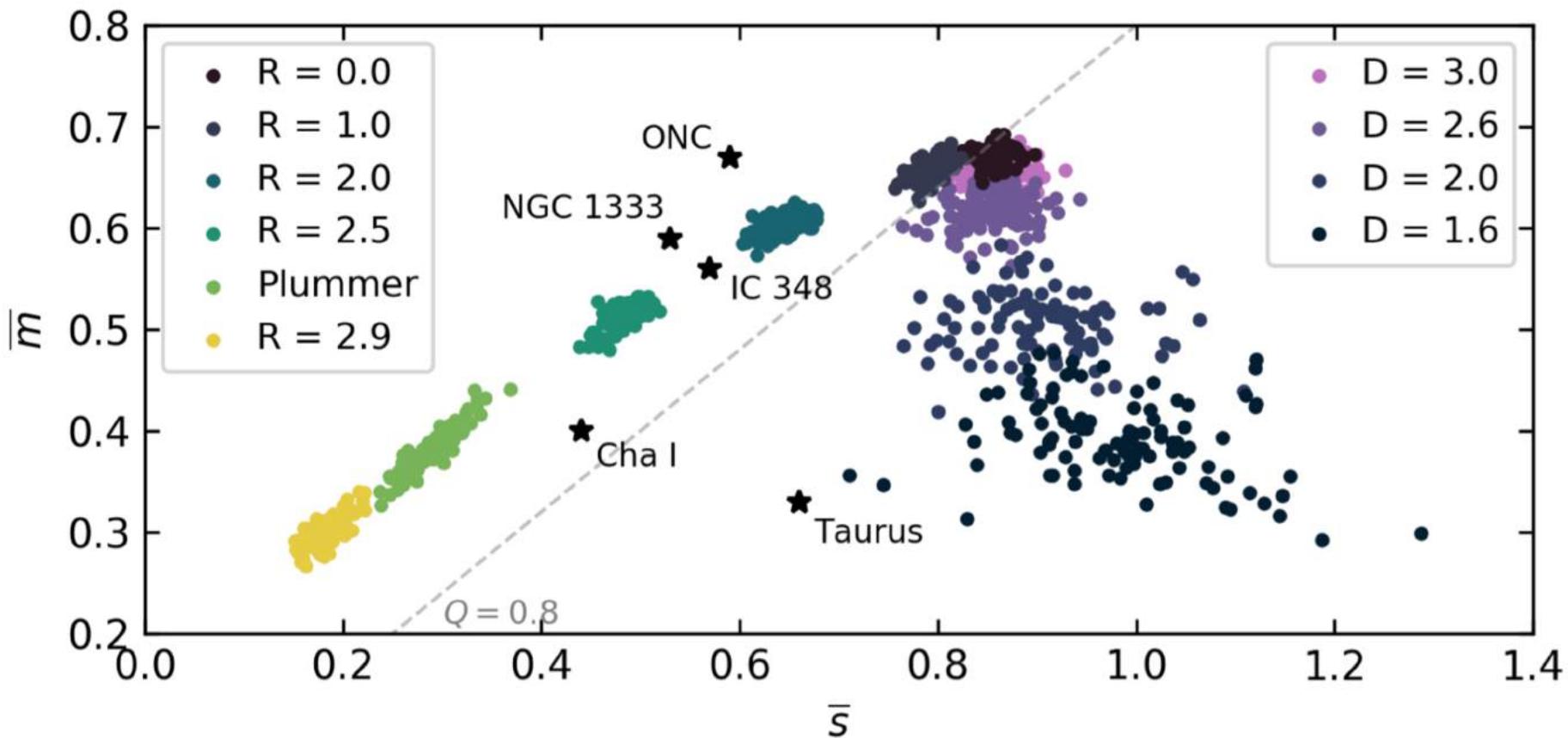


Q-parameter

- Dynamics rapidly erases substructure (Scally & Clarke 2002; Goodwin & Whitworth 2004; Parker & Meyer 2012; Parker, Wright, Goodwin & Meyer 2014)



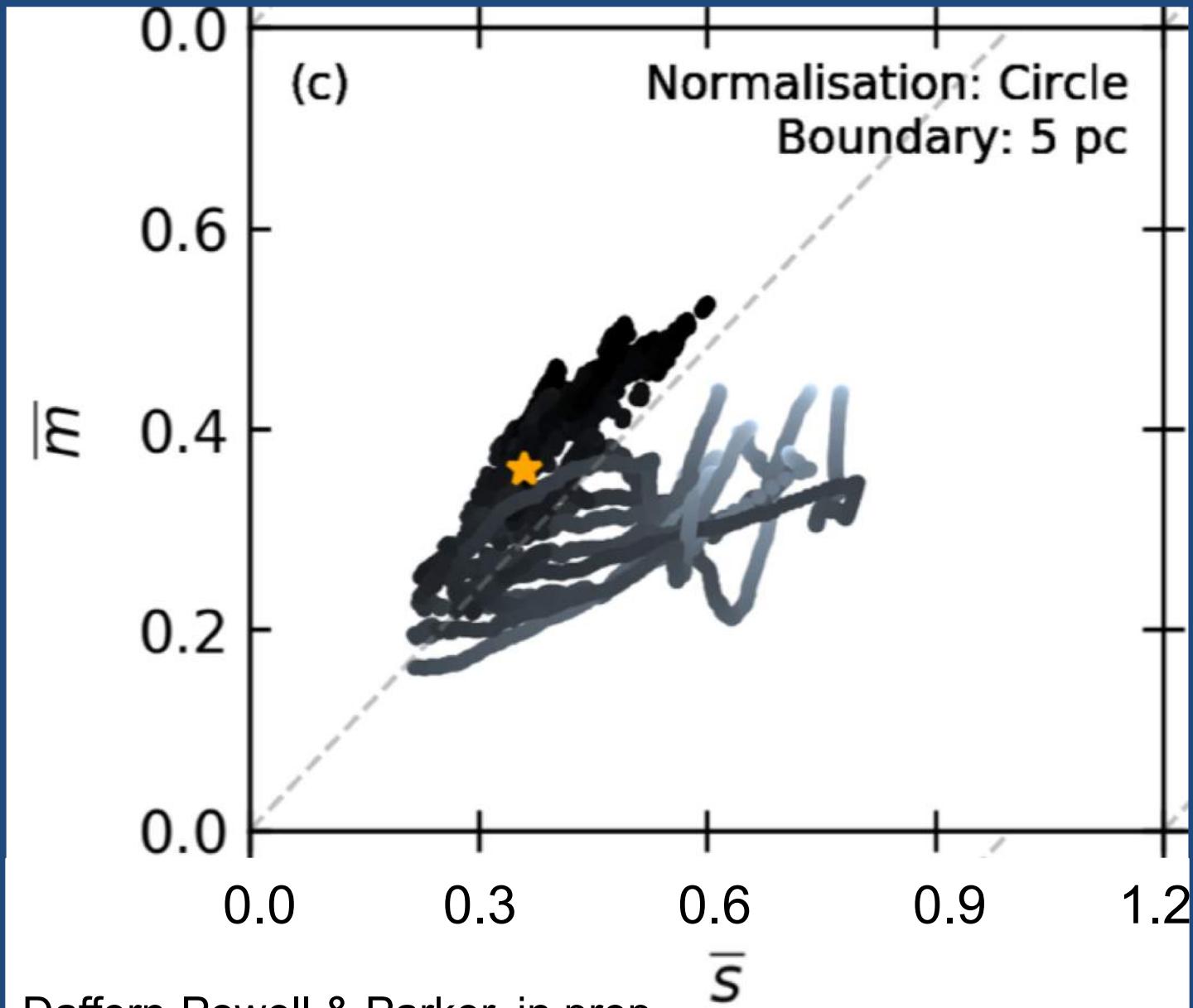
Dynamical evolution



mbar – sbar plot (Cartwright 2009, Lomax et al 2018)

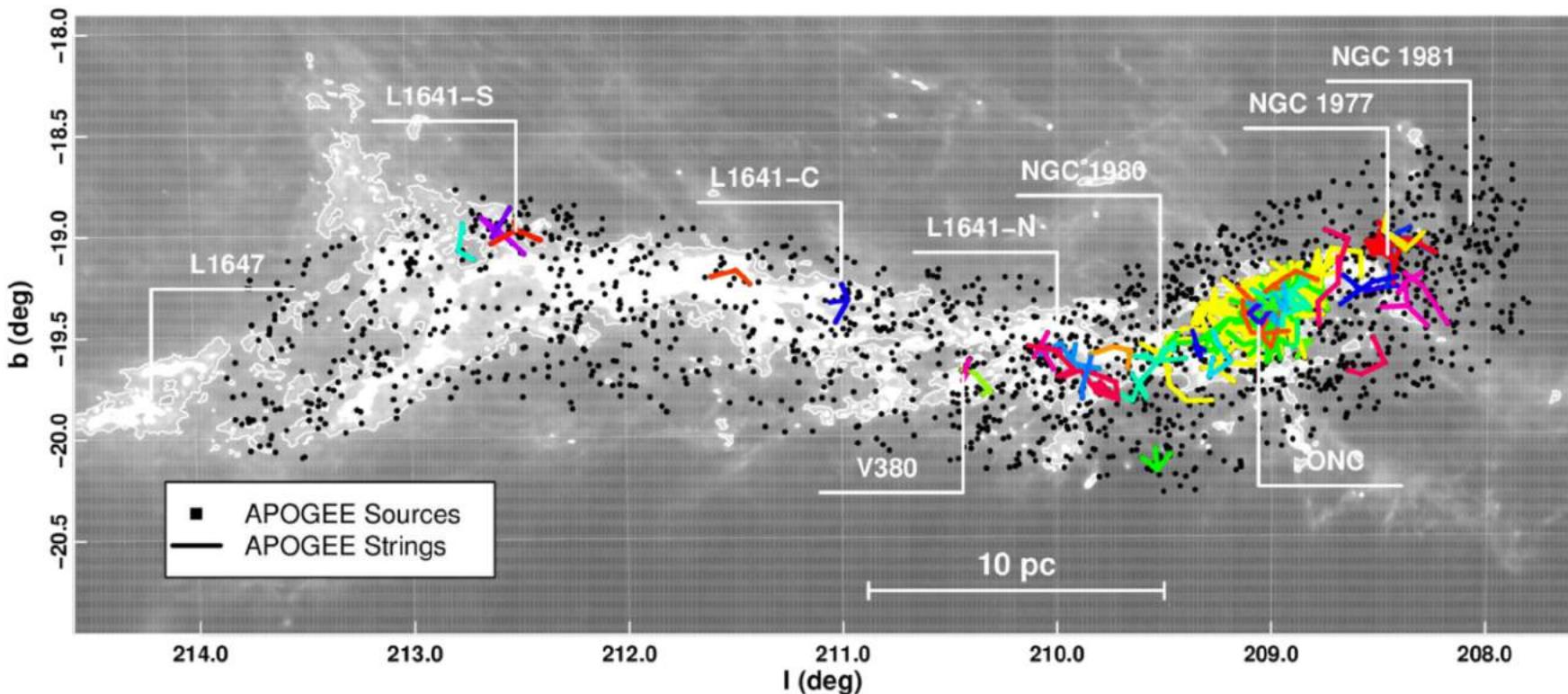


Dynamical evolution



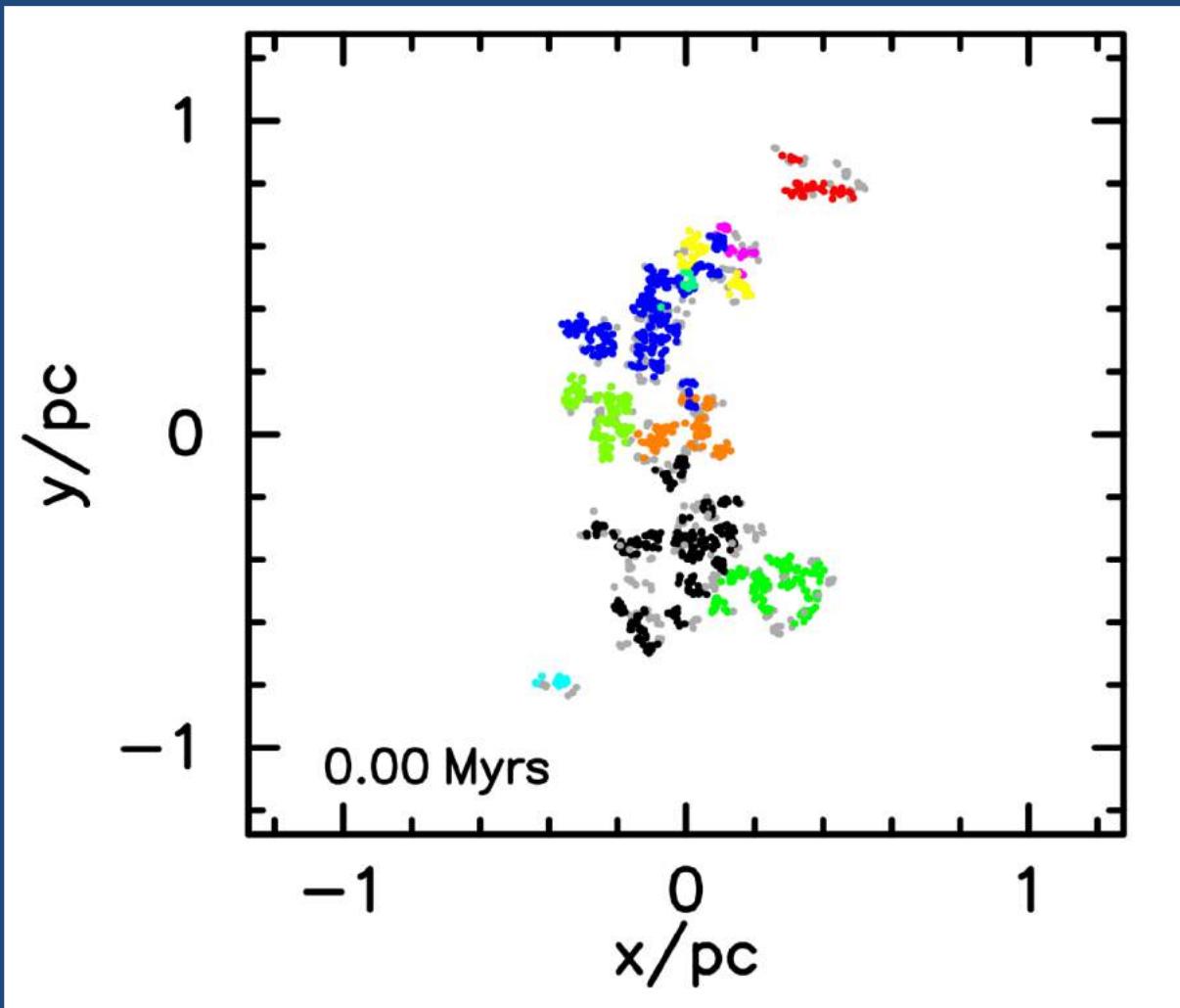


Friends of Friends



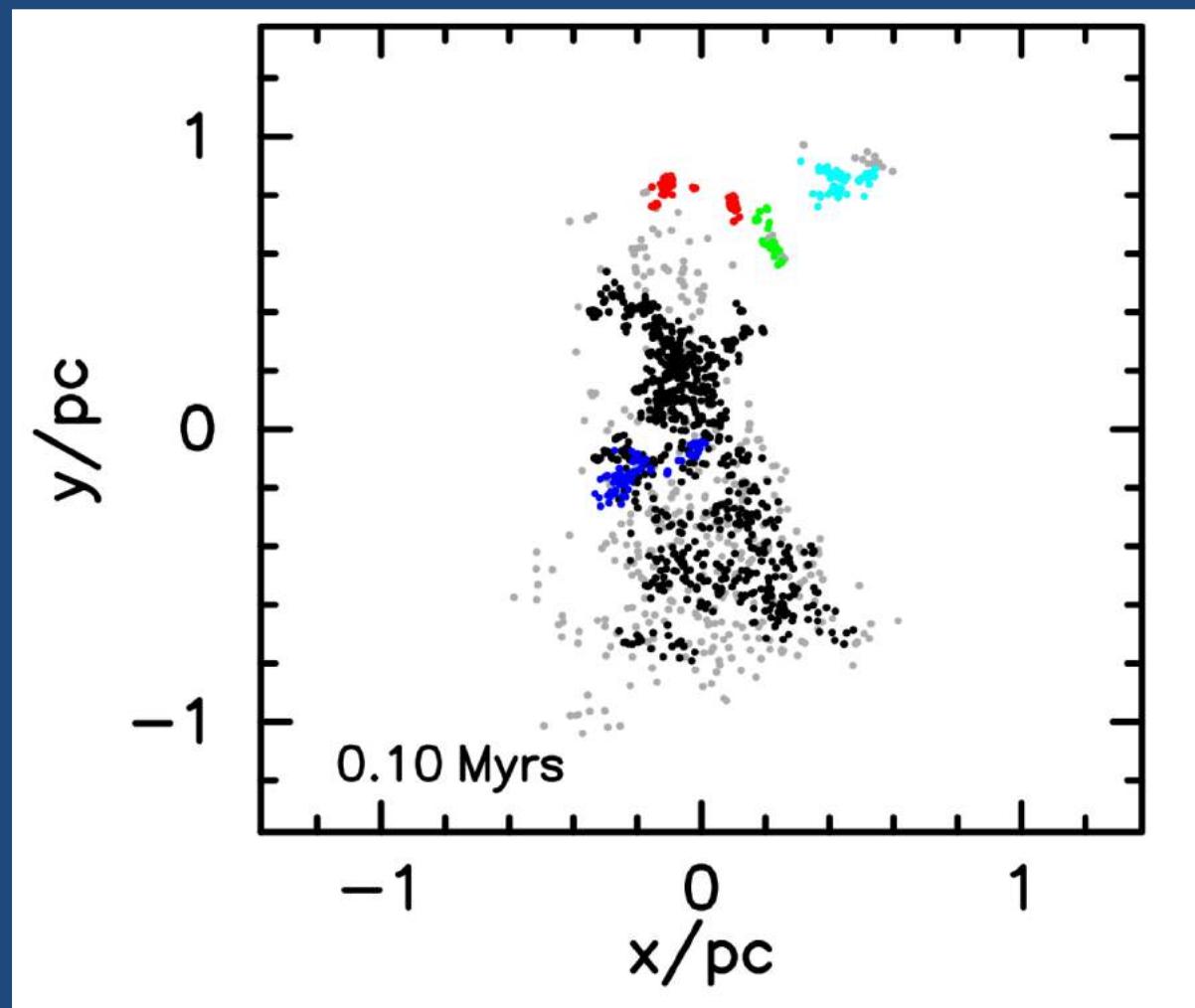


Friends of Friends



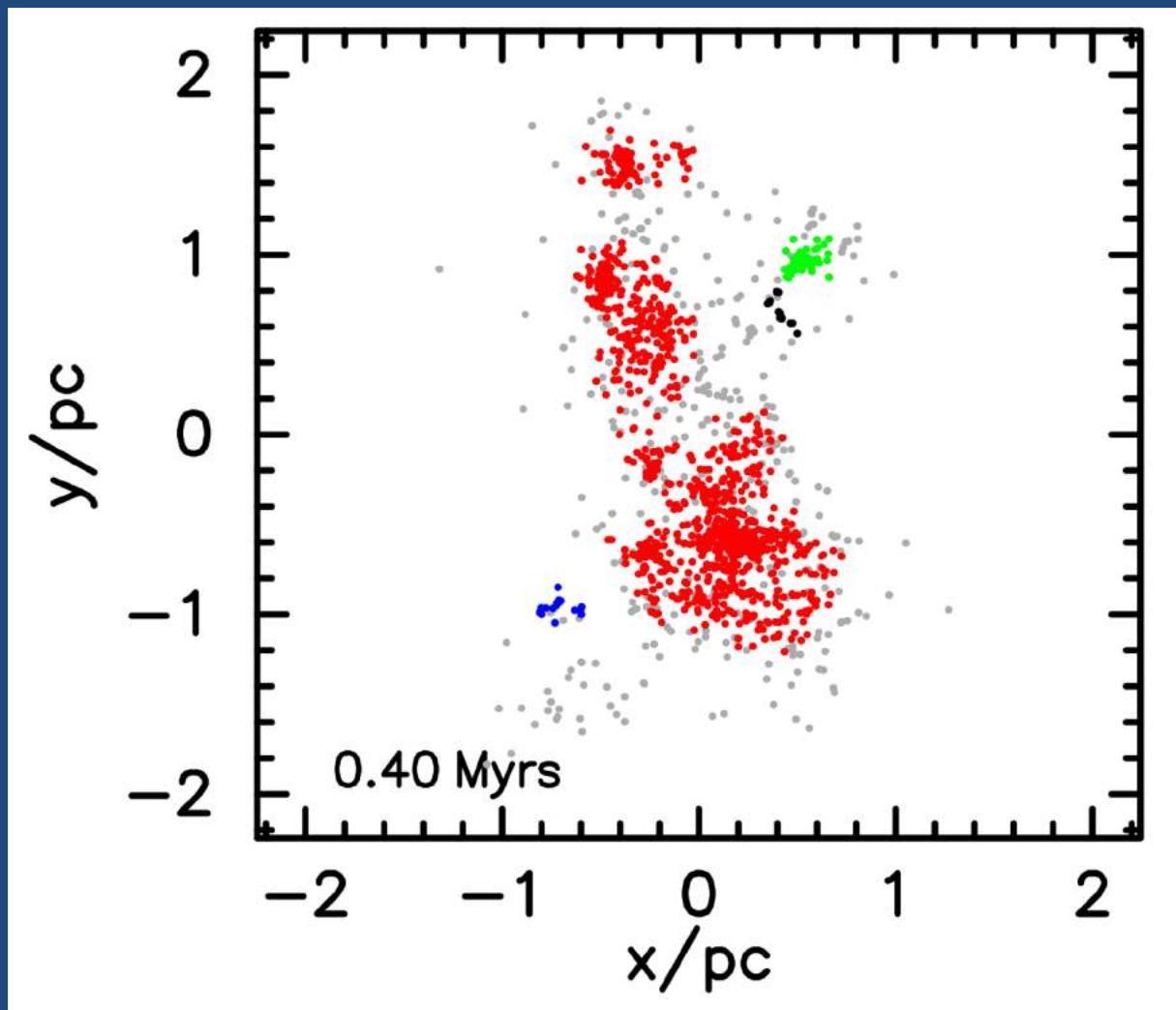


Friends of Friends



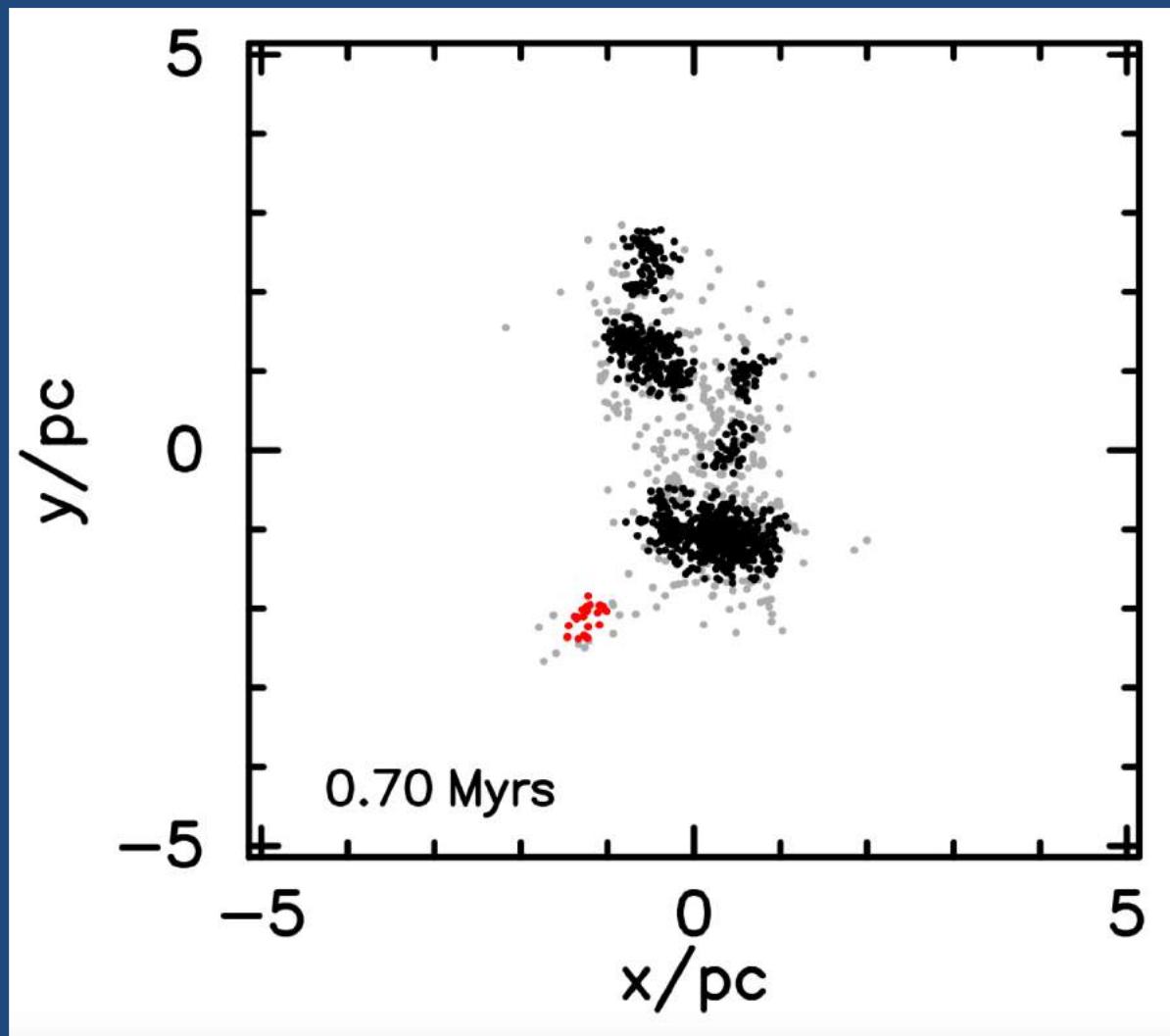


Friends of Friends



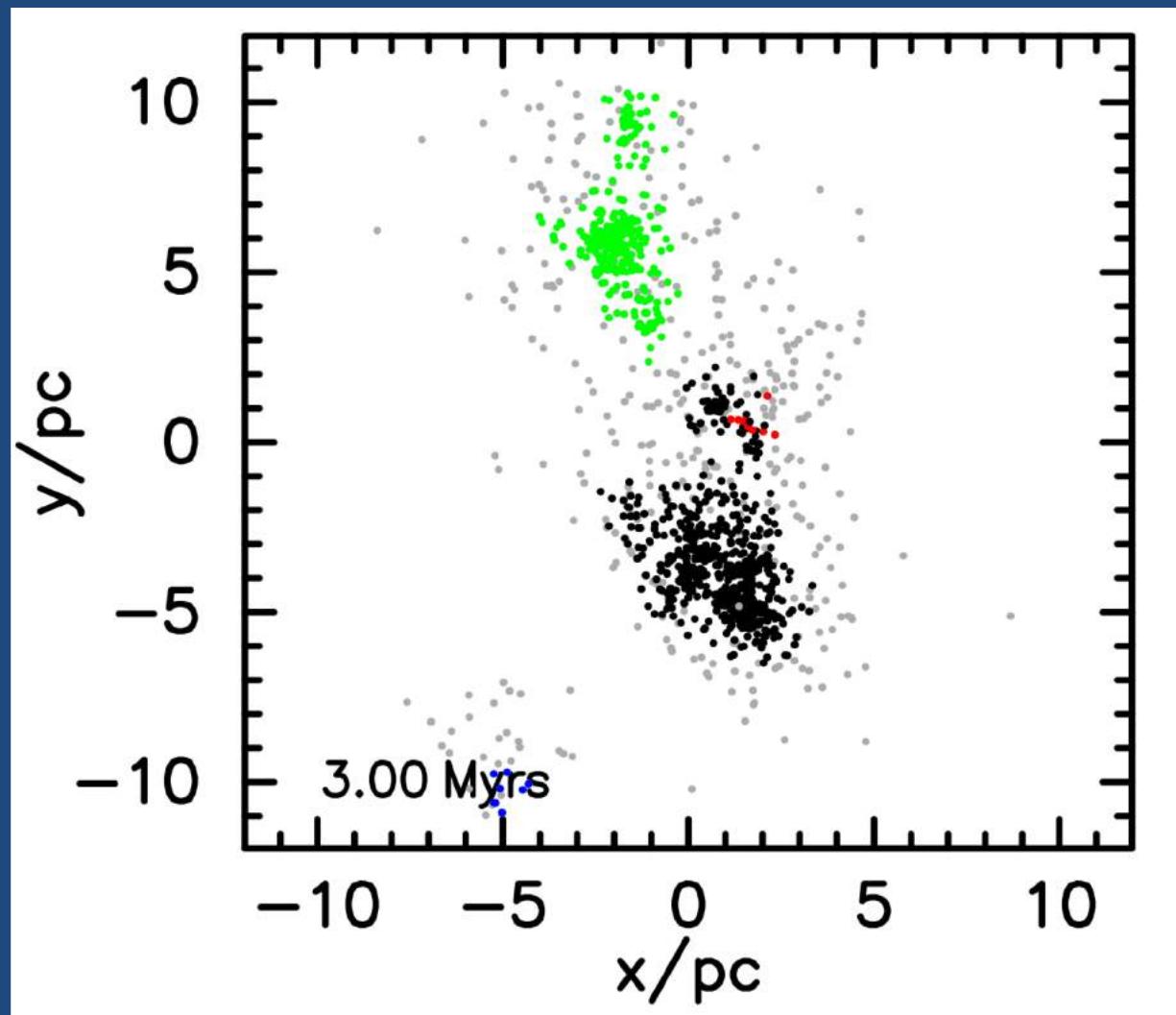


Friends of Friends



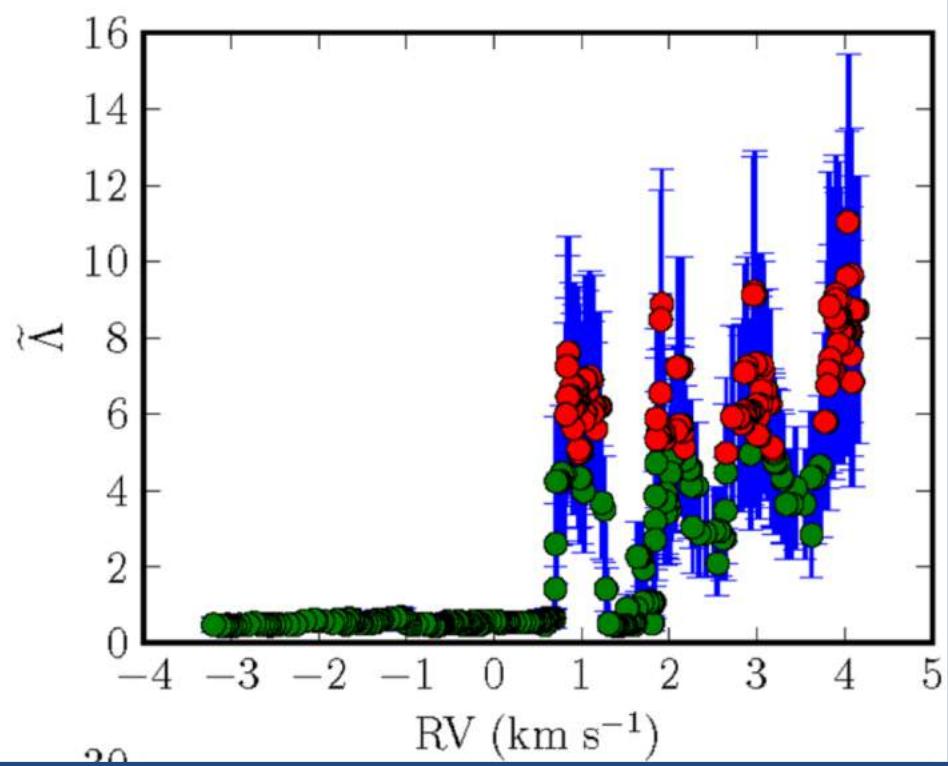
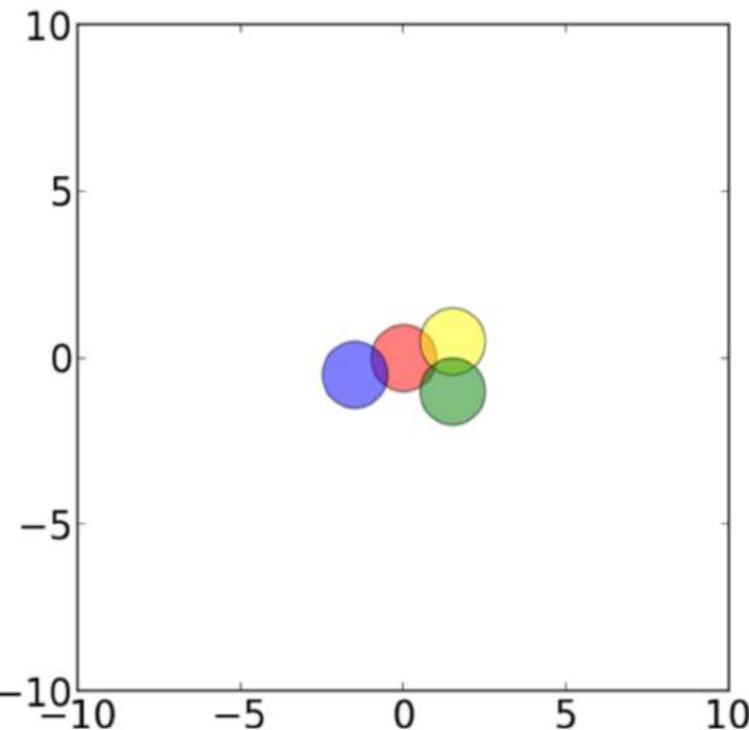


Friends of Friends



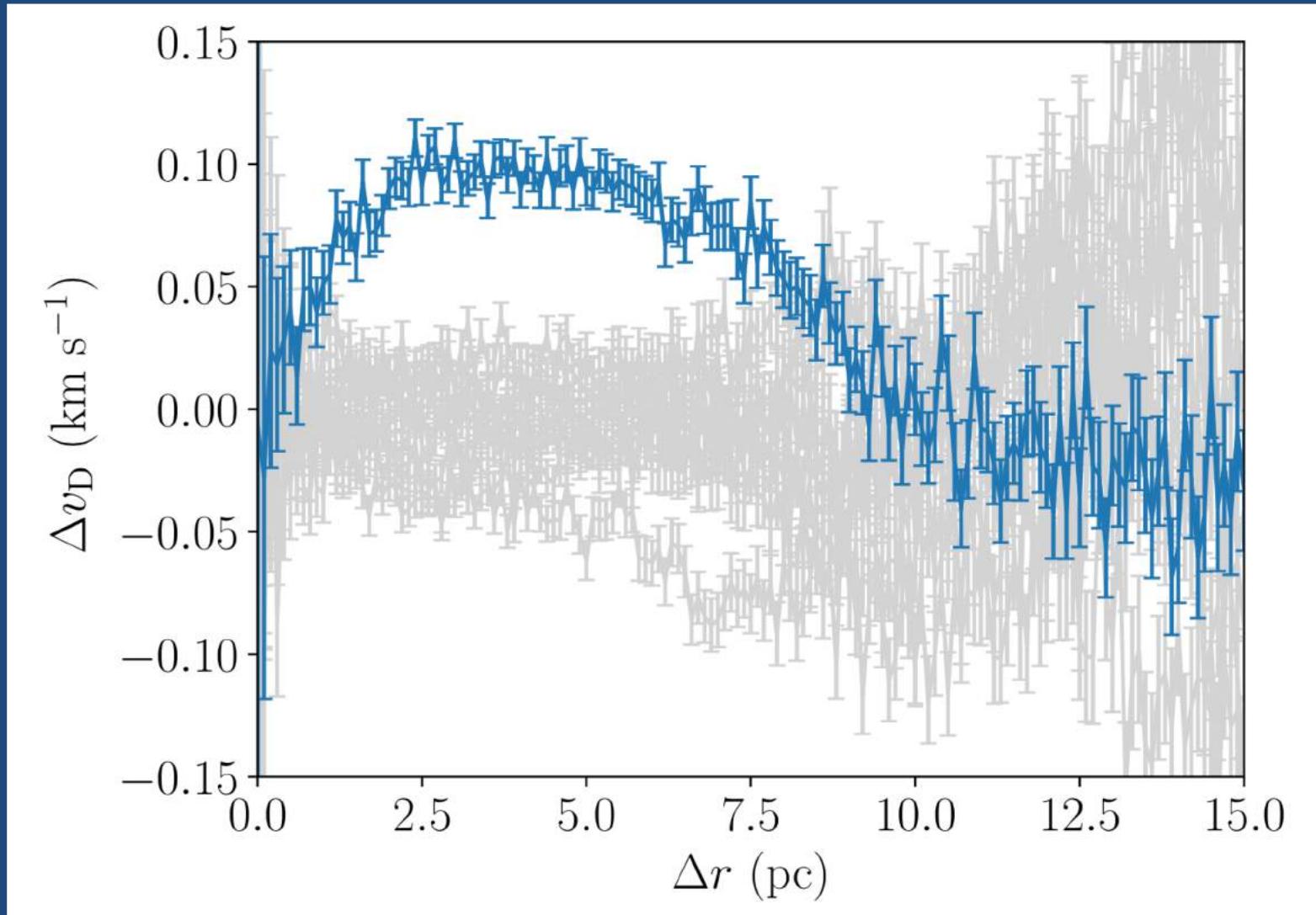


Radial velocity segregation



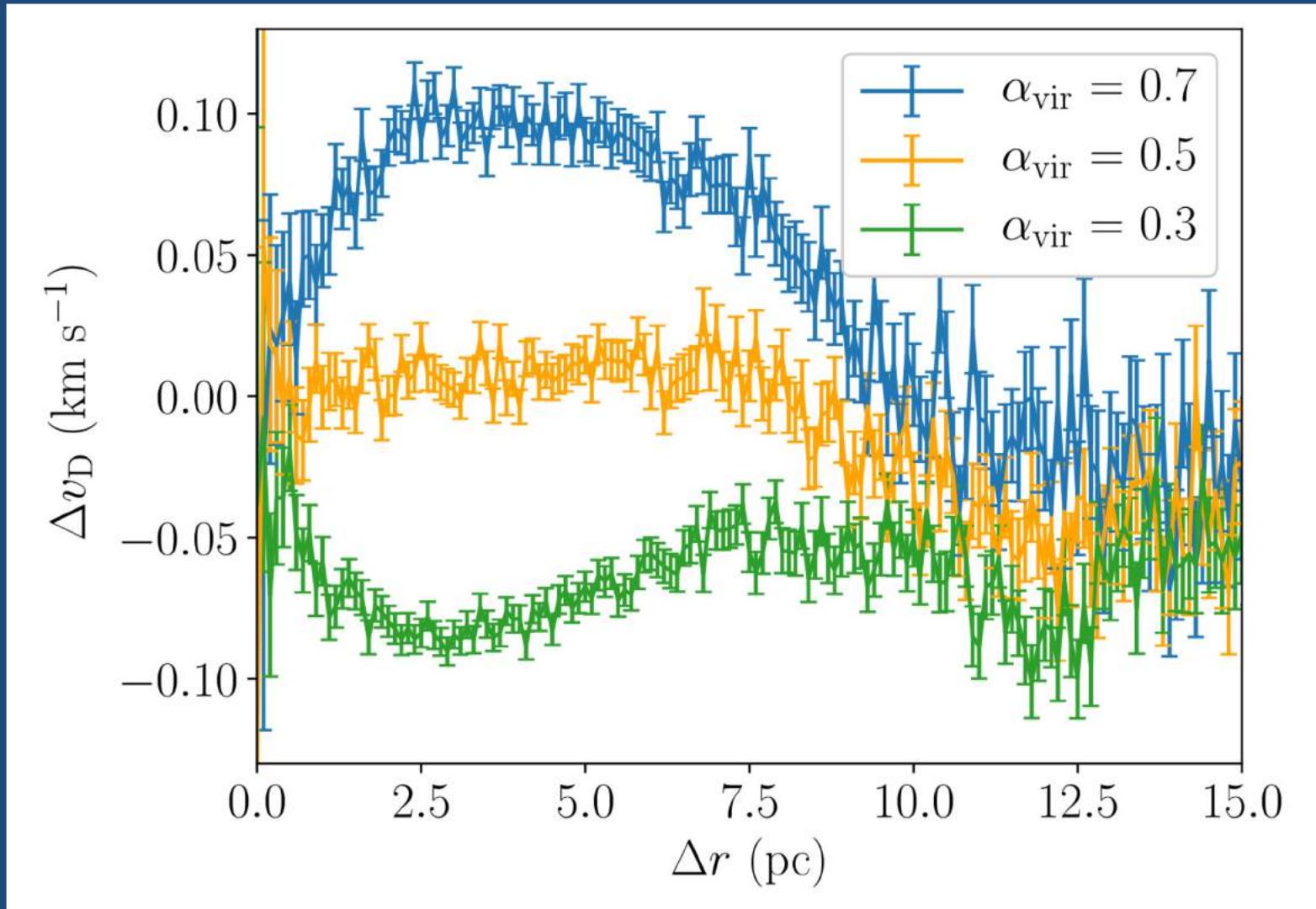


Arnold Velocity Structure Analysis Tool





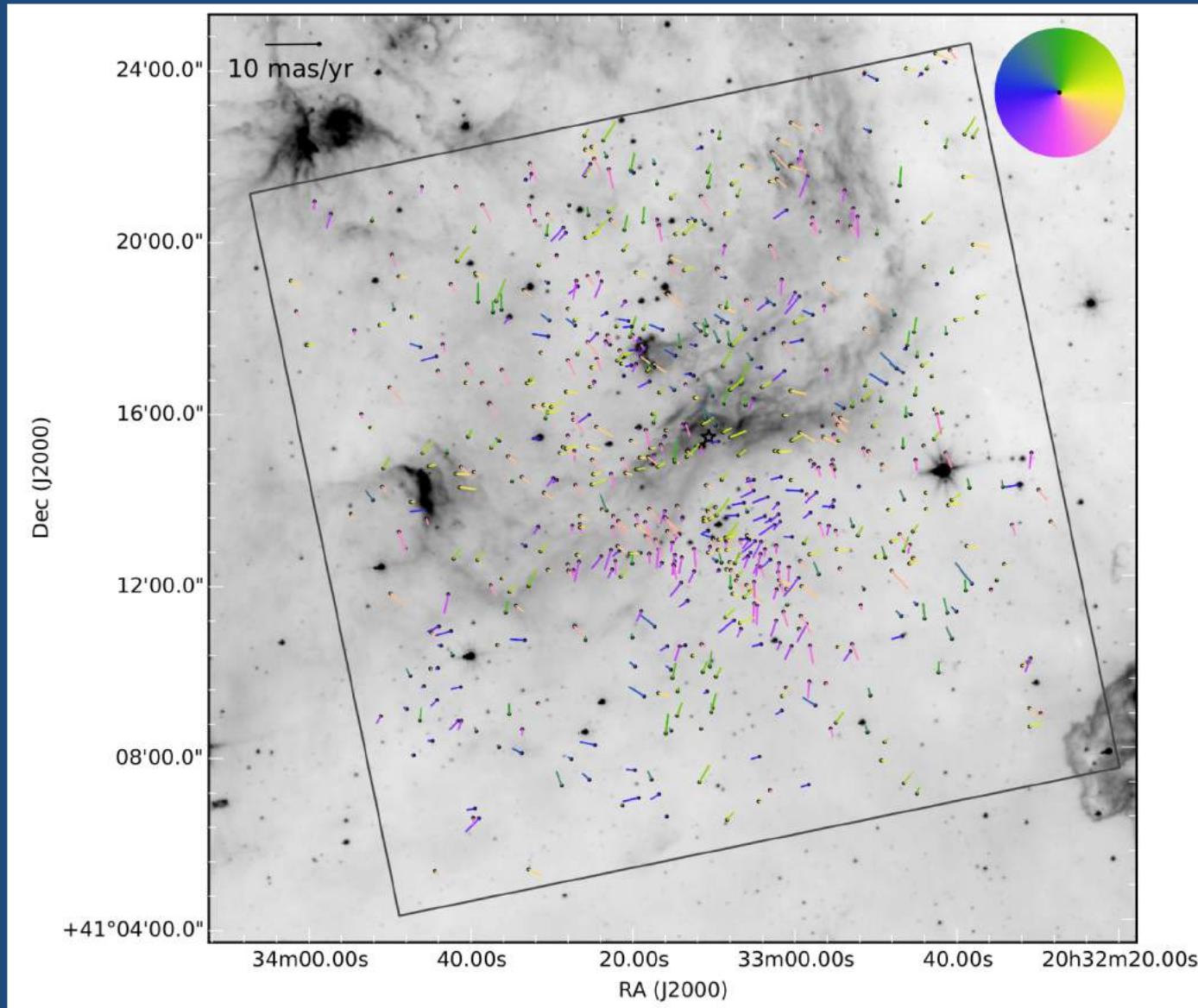
Arnold Velocity Structure Analysis Tool





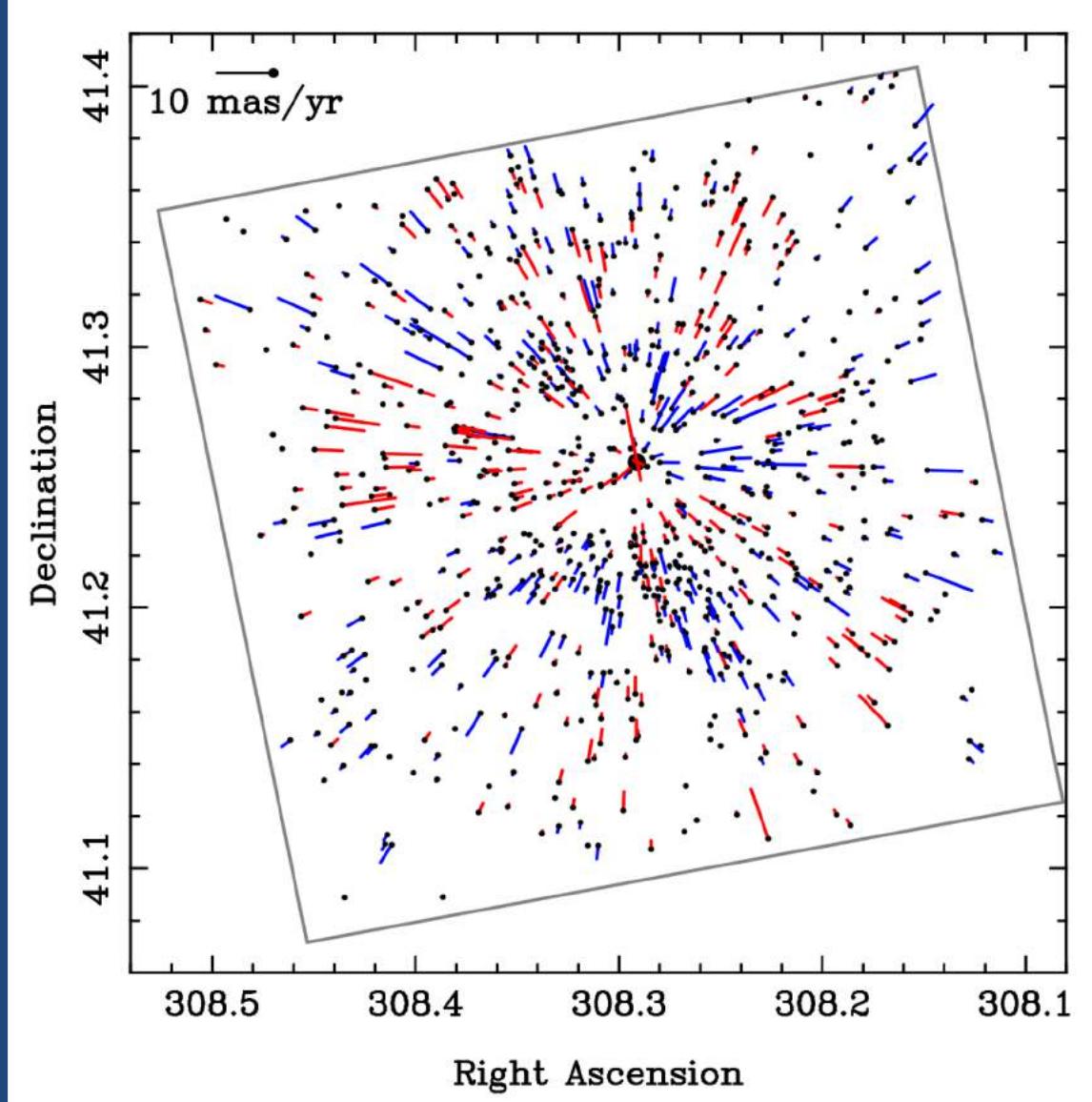
The
University
Of
Sheffield.

OB associations



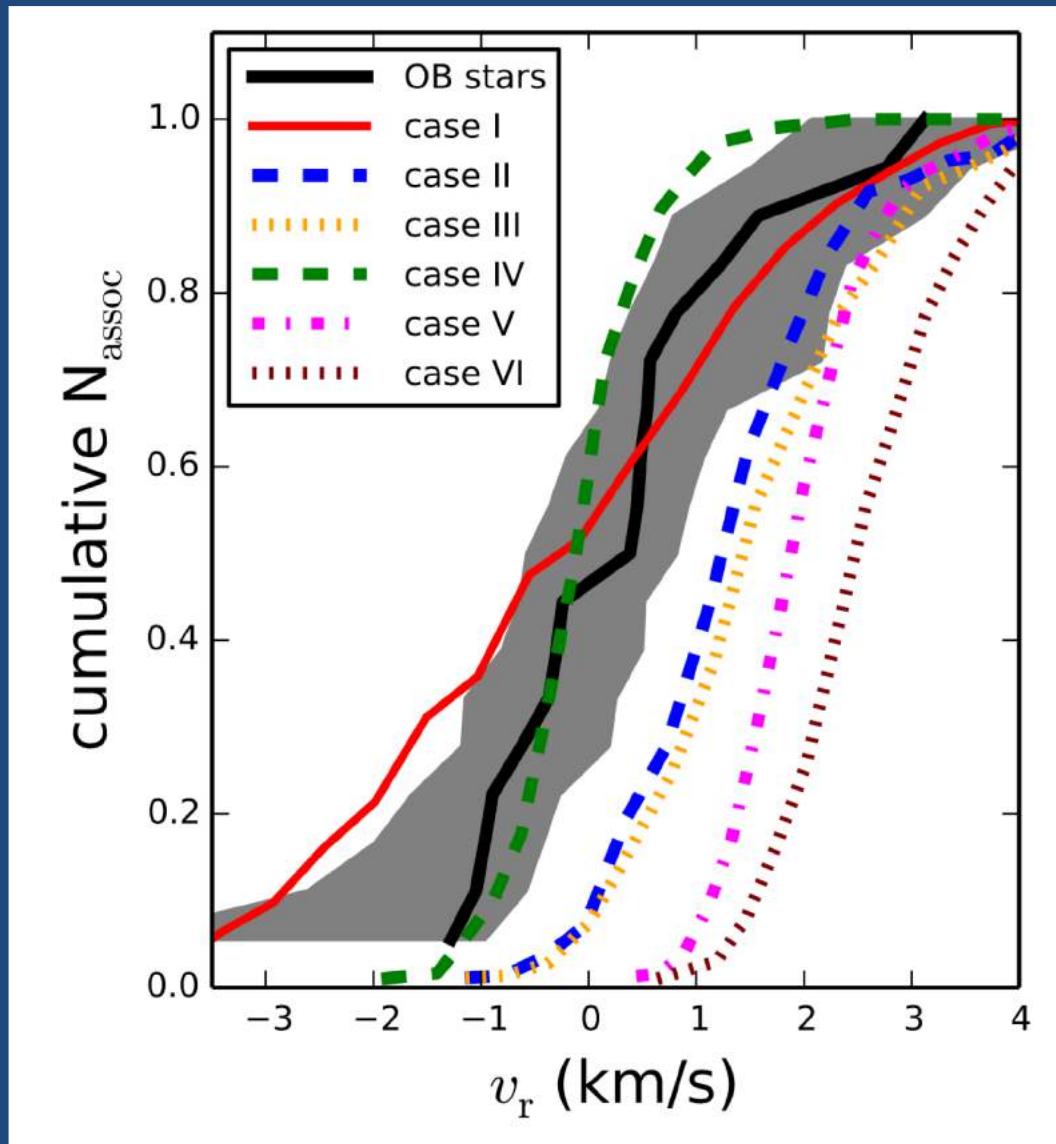


Proper motions



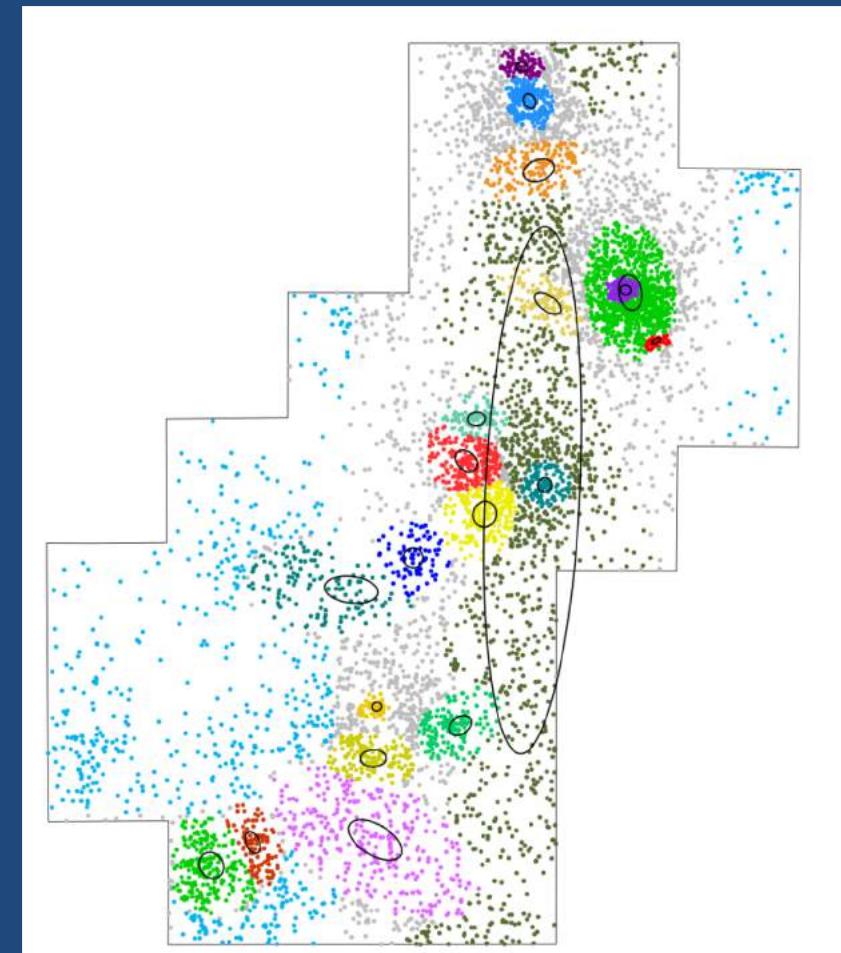
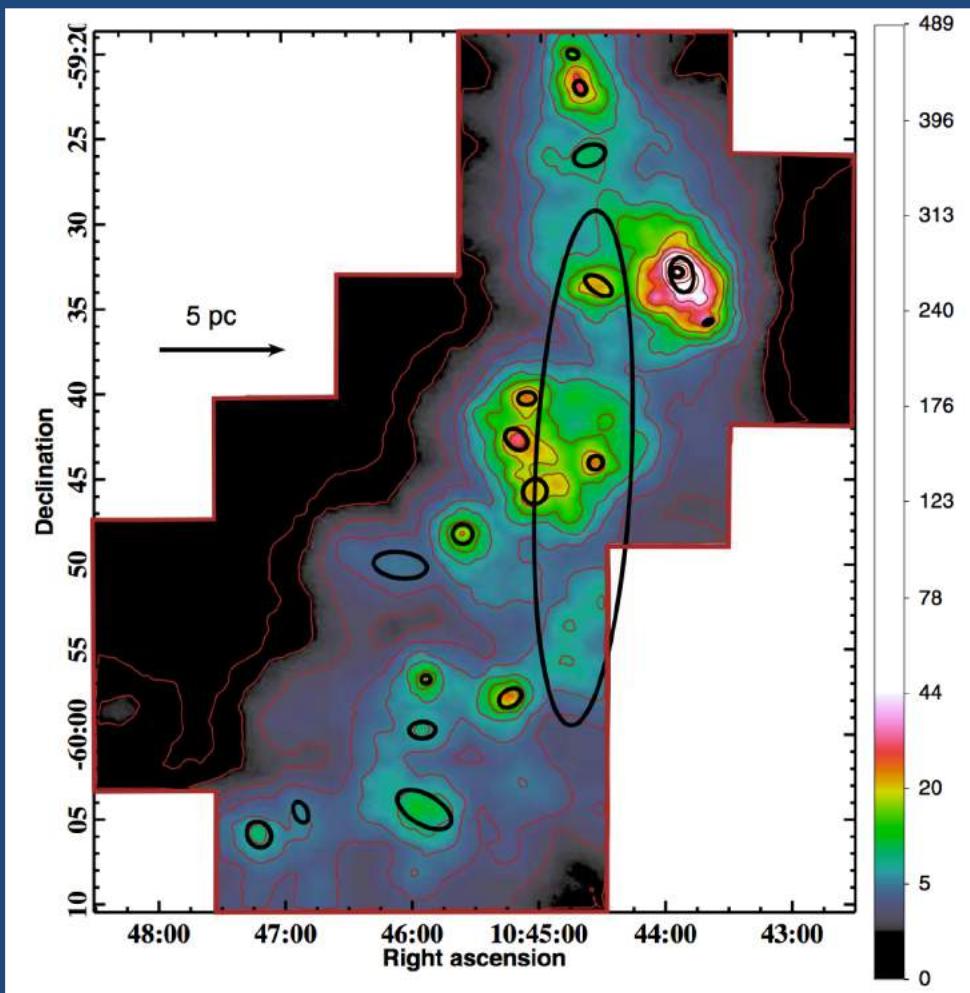


OB associations proper motions



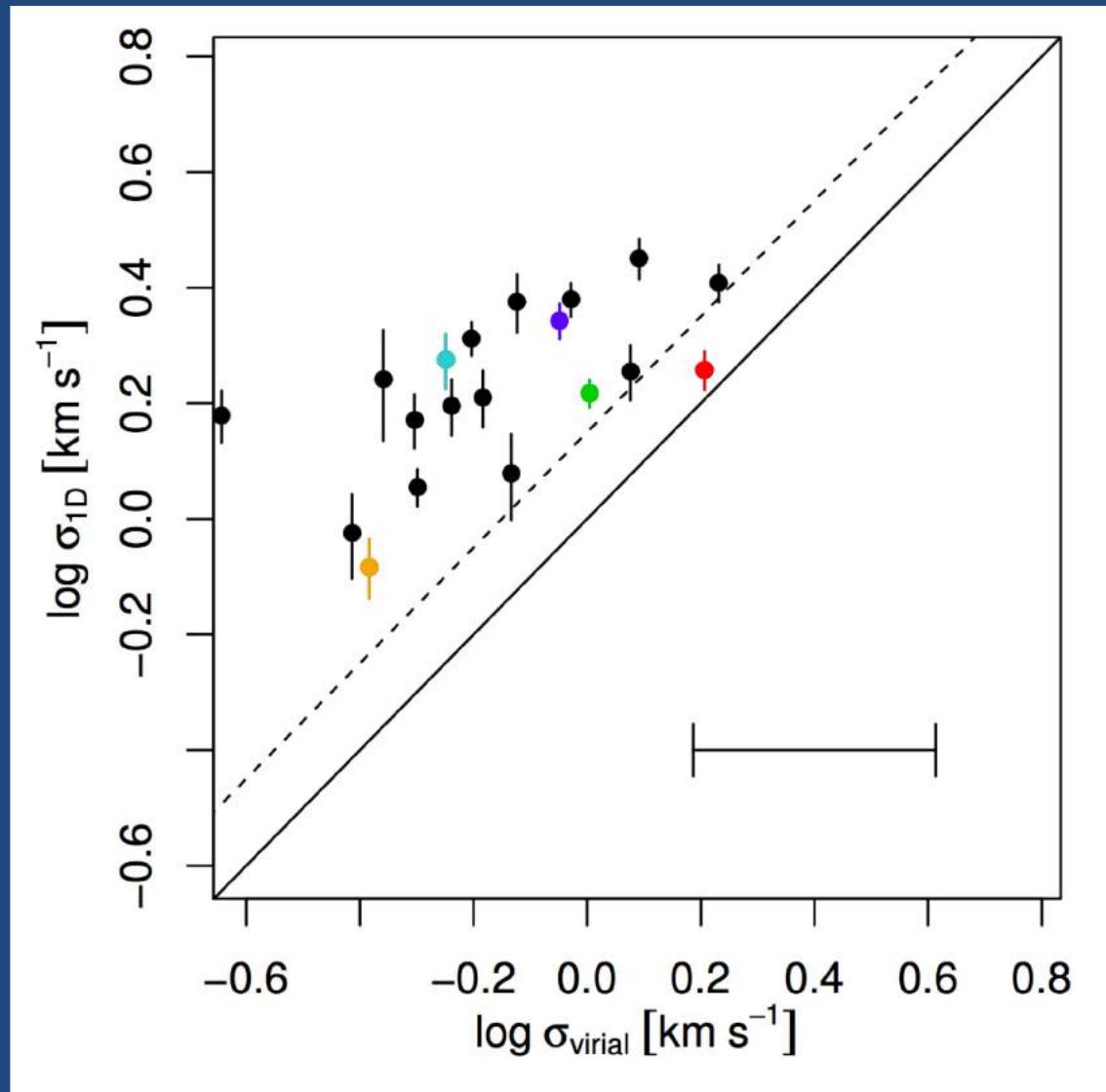


Finite mixture models





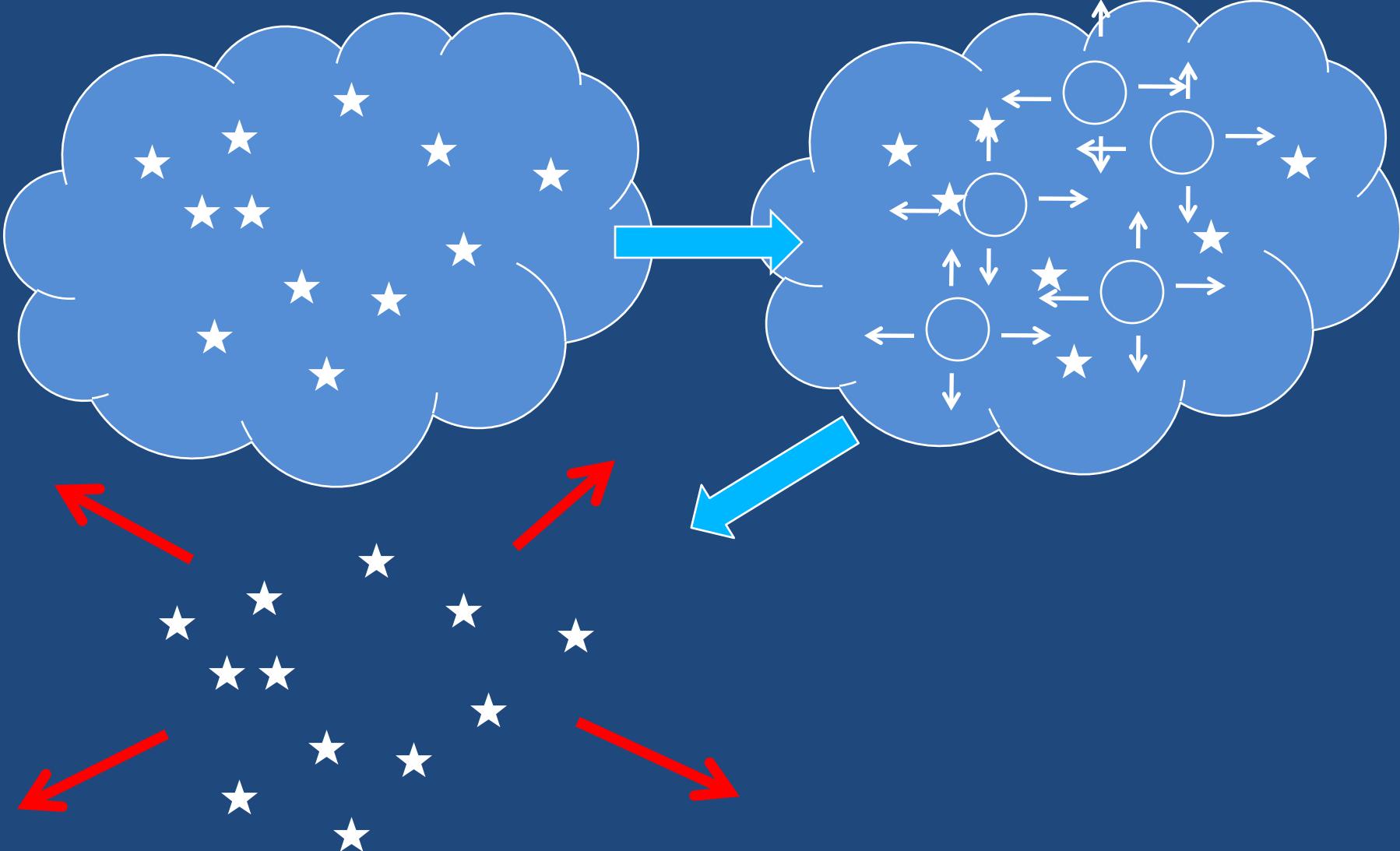
Supervirial velocities





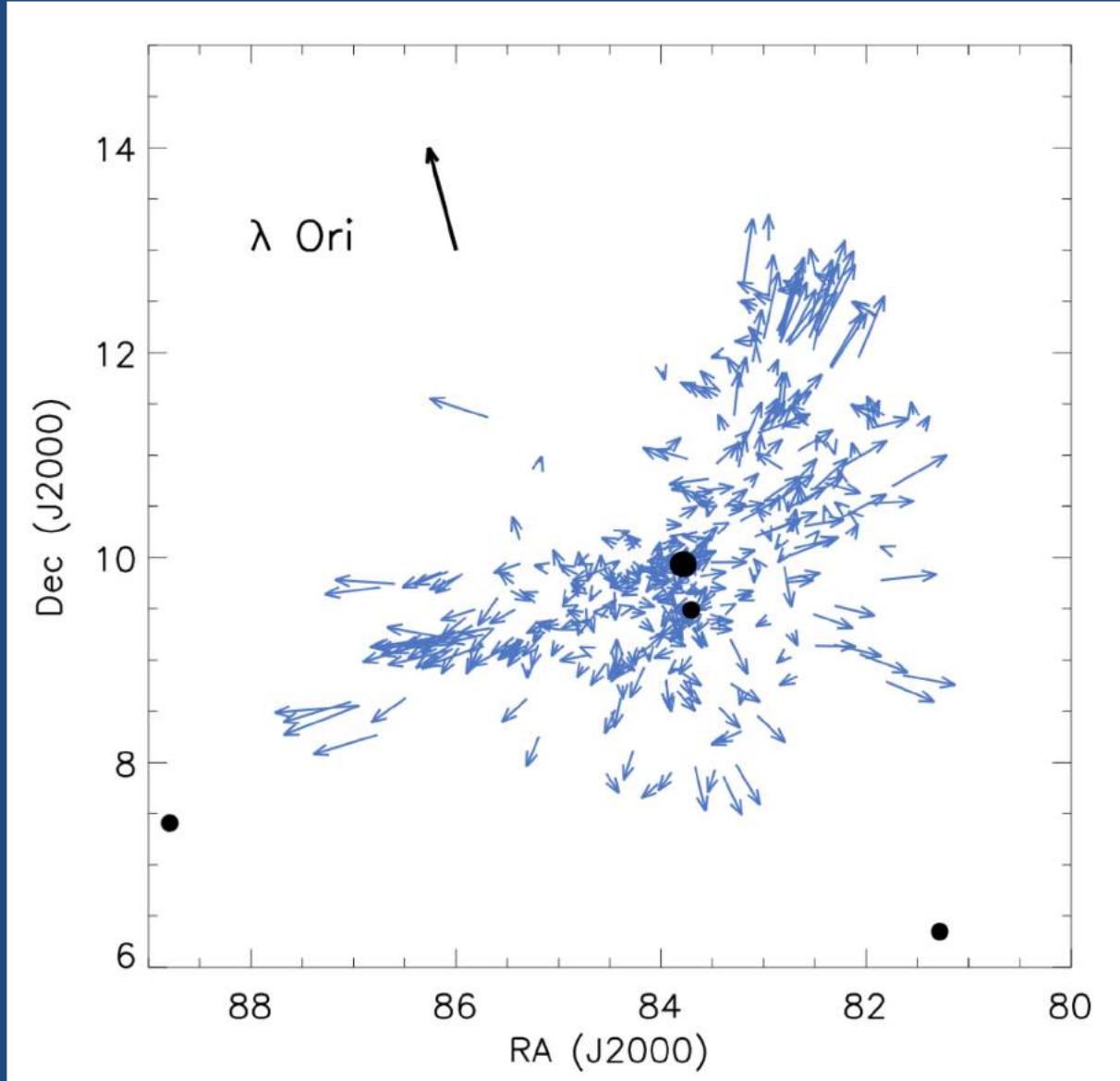
The
University
Of
Sheffield.

How do regions disperse?





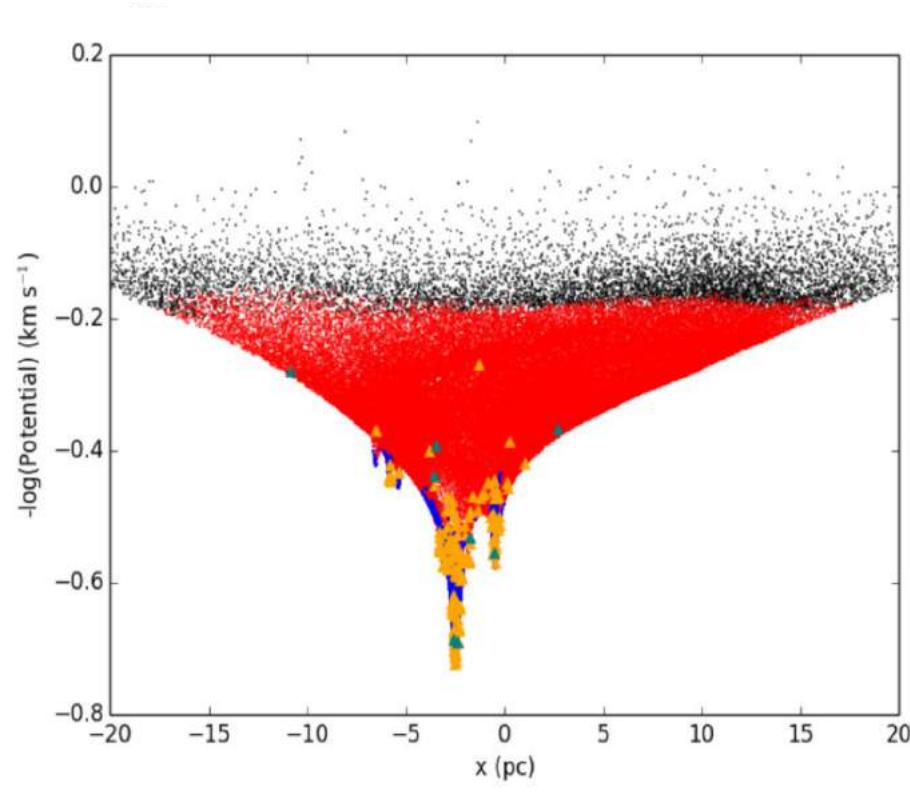
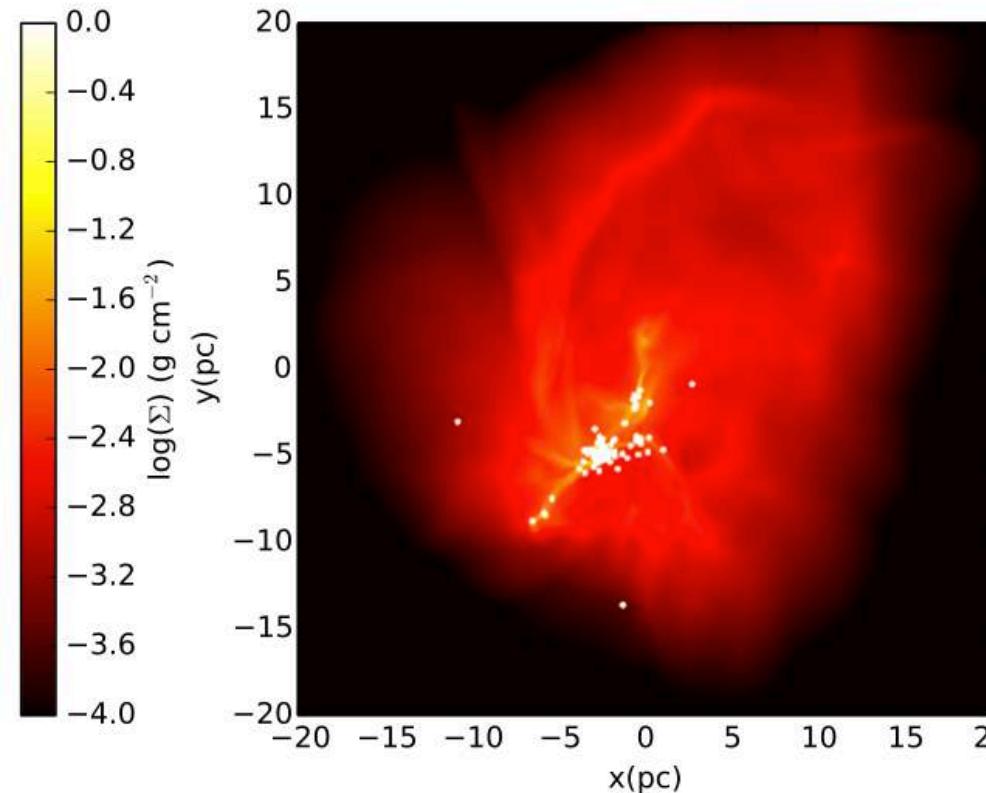
Proper motions





Feedback

Control Run I from Dale et al 2014

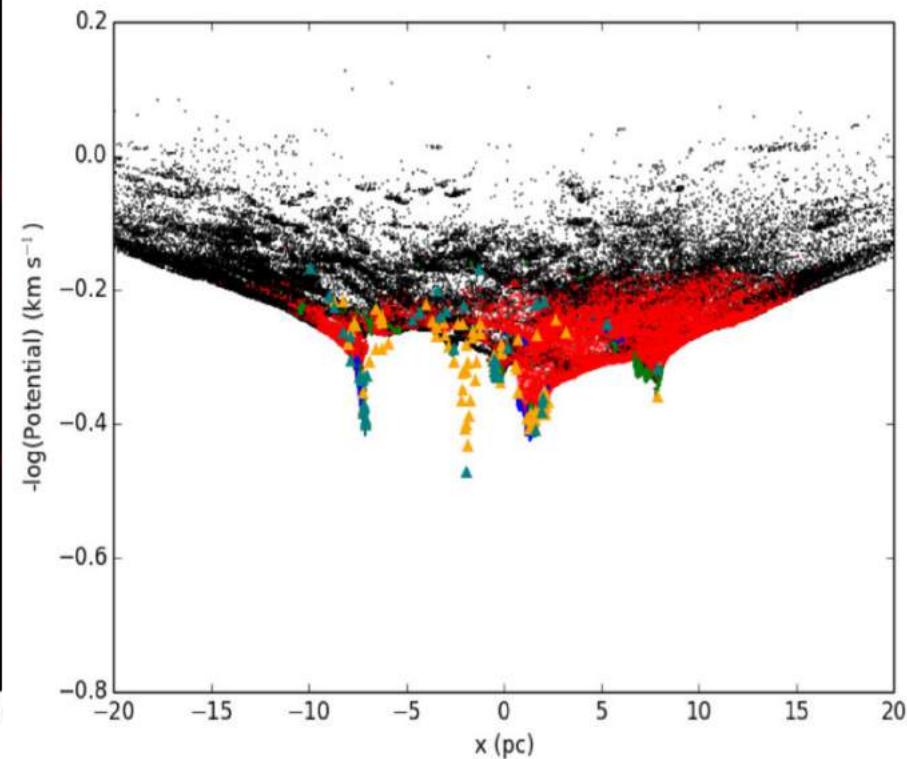
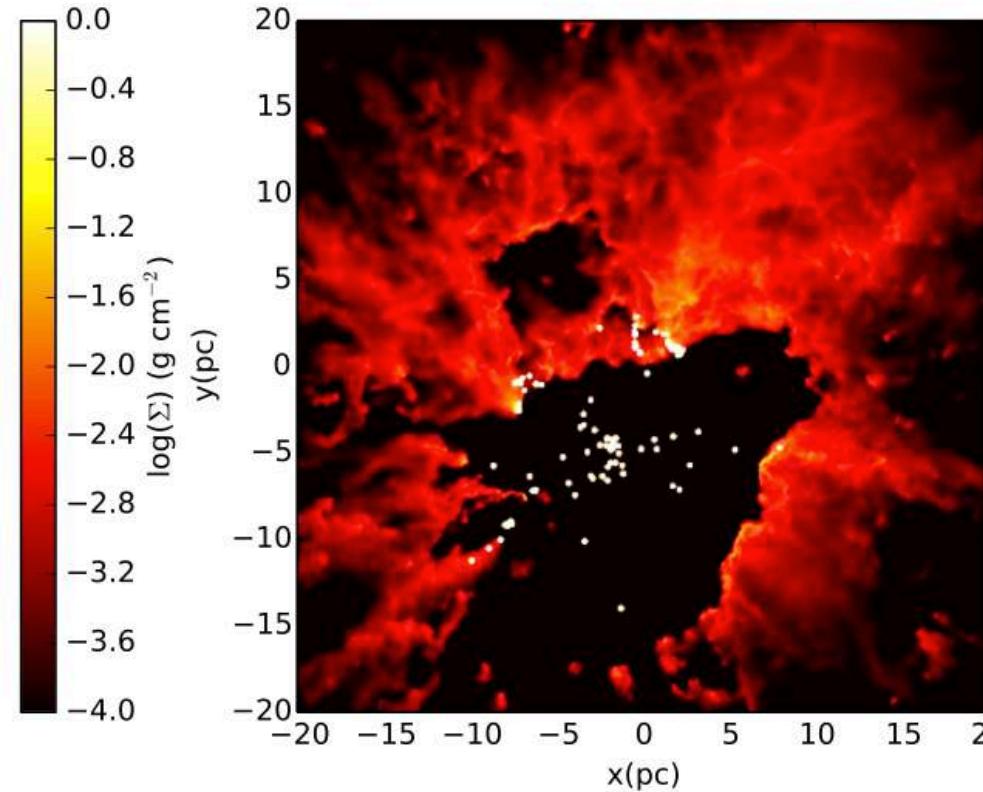


(Dale et al 2012,2014,2015)



Feedback

Dual-feedback Run I from Dale et al 2014

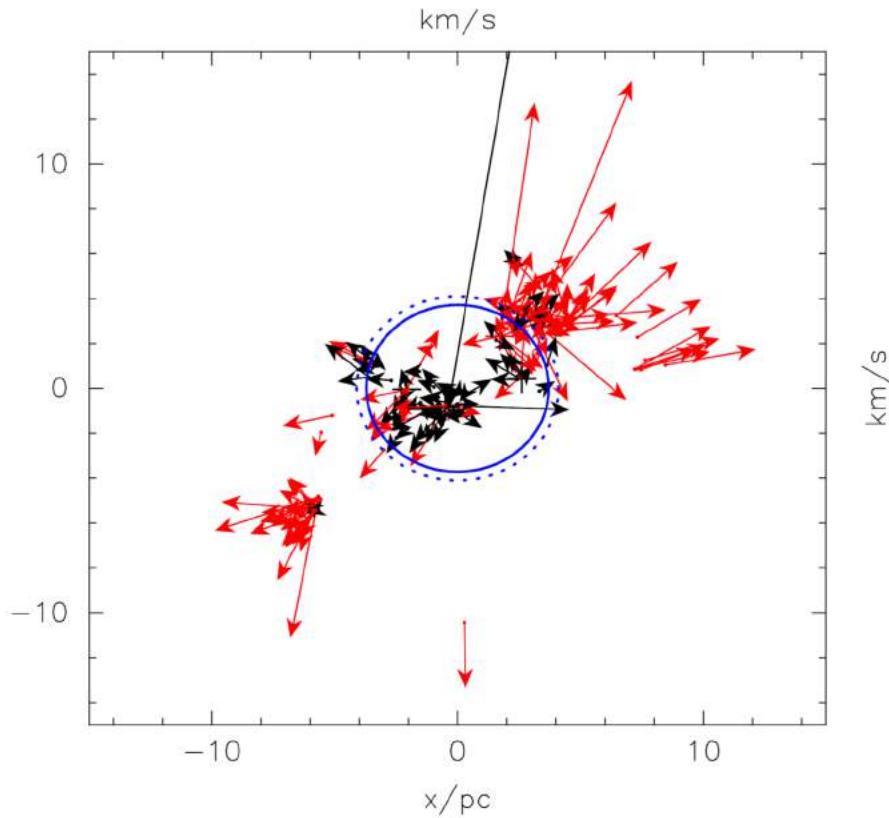
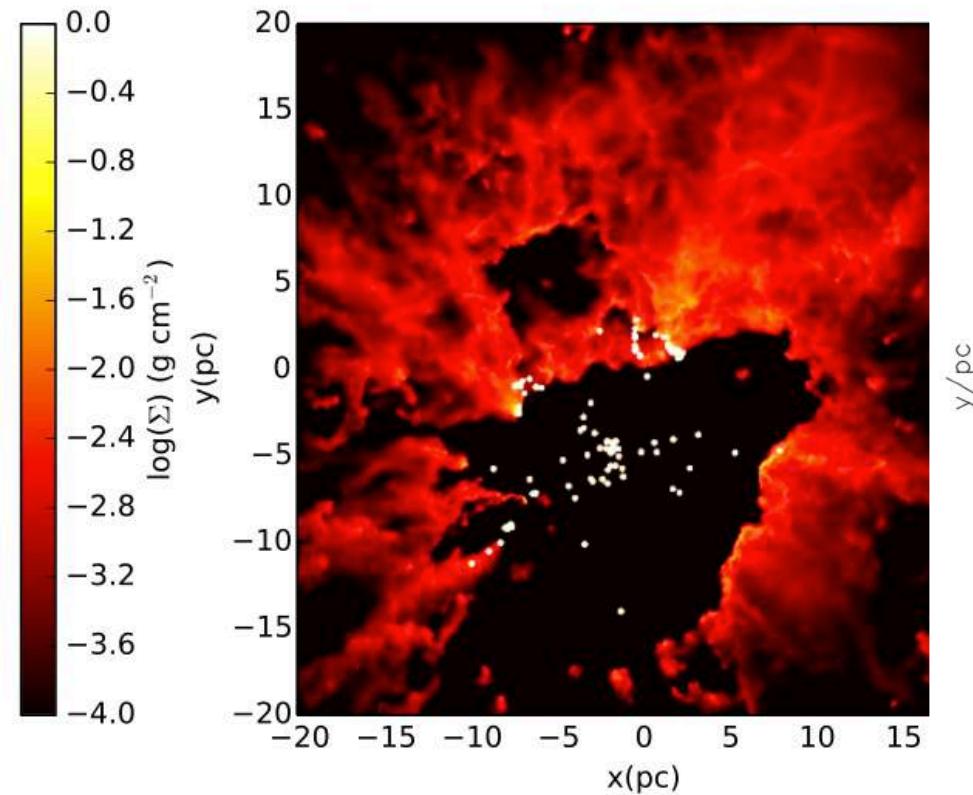


(Dale et al 2012, 2014, 2015; see also e.g. Tanaka et al 2018; Geen et al 2018)



Feedback

Dual-feedback Run I from Dale et al 2014



(See also Zamora-Aviles et al 2019)

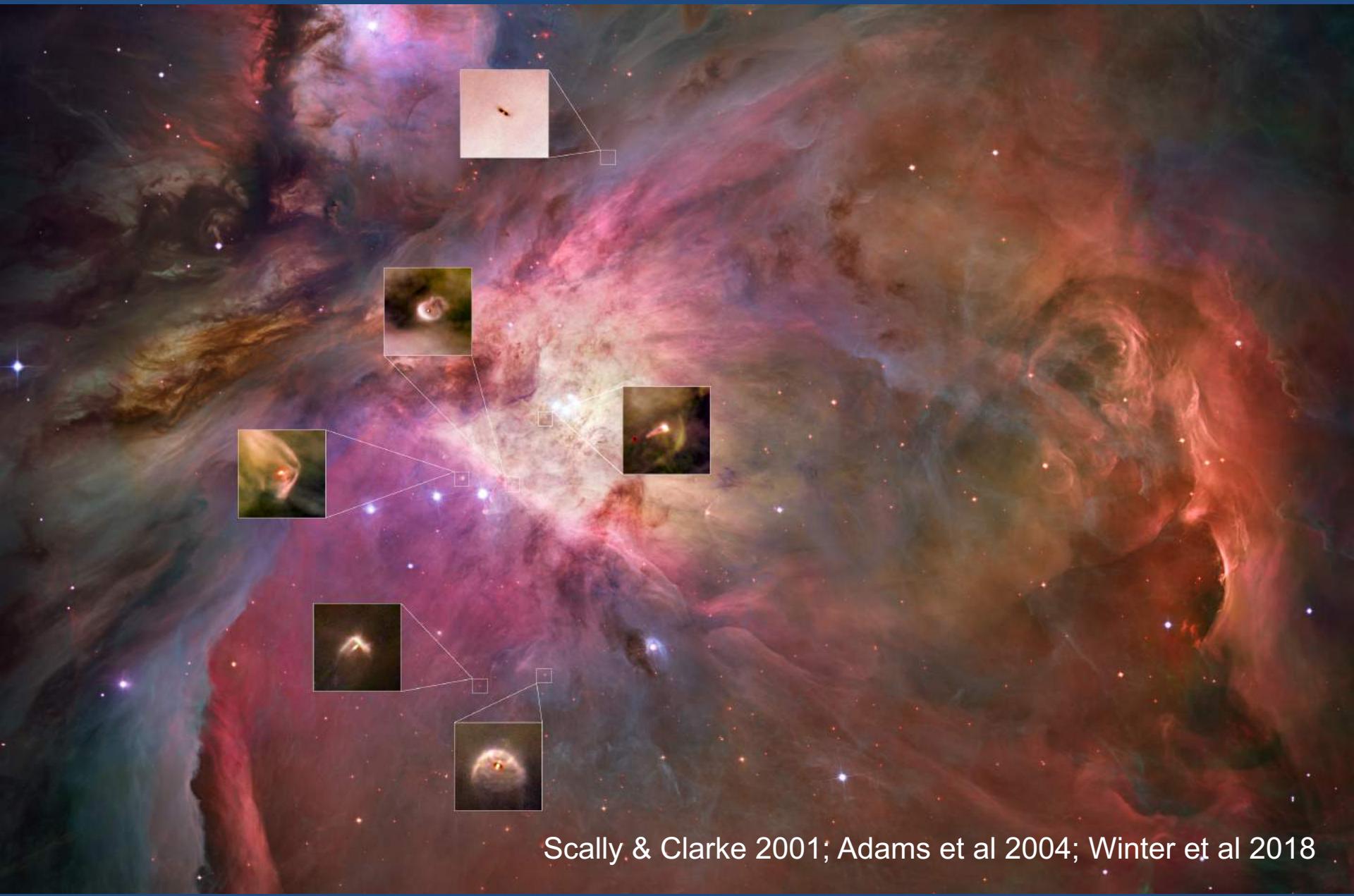


The
University
Of
Sheffield.

Why does this matter?



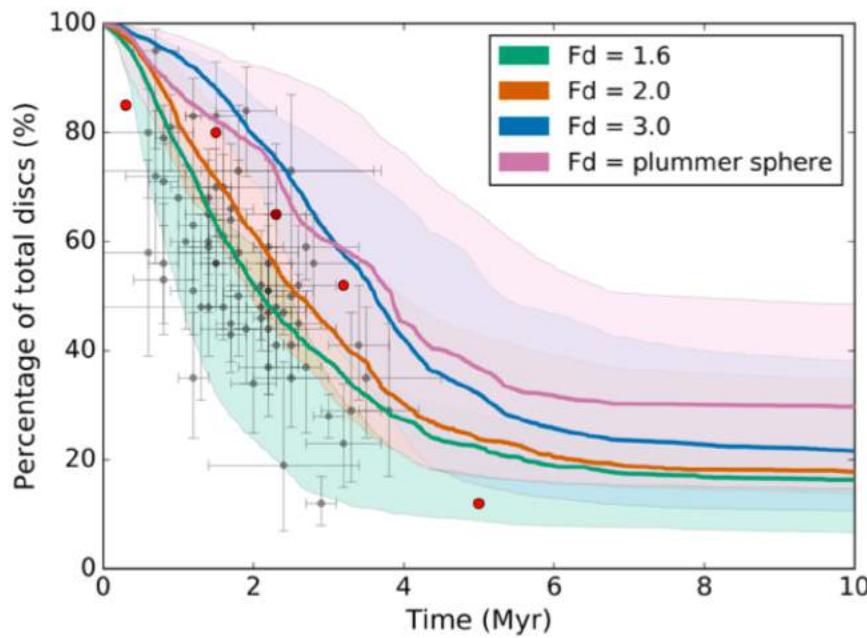
Protoplanetary disc destruction



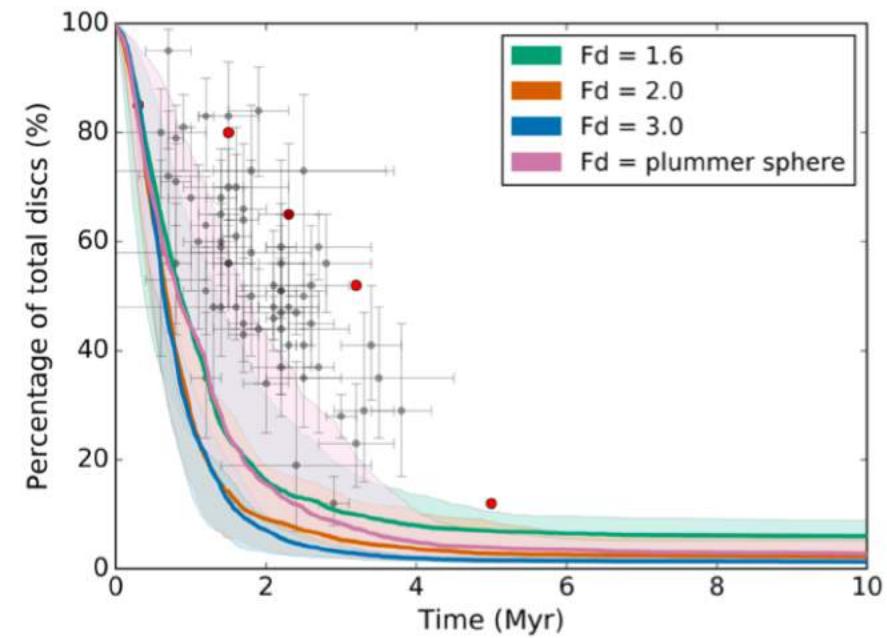
Scally & Clarke 2001; Adams et al 2004; Winter et al 2018



Disc destruction from radiation



(a) Density = $10 \text{ M}_\odot \text{ pc}^{-3}$



(b) Density = $100 \text{ M}_\odot \text{ pc}^{-3}$



Summary

- Tools to quantify spatial/kinematic distributions are useful, but exercise caution in interpreting them!
- Globally, star-forming regions not expanding or contracting
- Individual subclusters are expanding
- Due to feedback?
- Planet formation affected more in substructured regions